

BULLETIN

OF THE

INTERNATIONAL RAILWAY CONGRESS

ASSOCIATION

(ENGLISH EDITION)

[625 .251]

Research into a method of calculating the stopping distance in the case of goods trains retarded by continuous compressed air brakes, with progressive charging of the brake cylinders,

(Continued *)

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II. SECOND PERIOD.

Brakes applied under constant pressure (Q kgr.), from the speed v_n (corresponding to the termination of the charging period) up to the stoppage of the train.

A. FIRST CASE.

The train continues to travel without skidding taking place on any of the wheels of the braked waggons in the train.

We will indicate by :

r_0 = the specific resistance of the train to rolling at low speed, expressed in kgr. per ton weight of train.

R_0 = total resistance to rolling at low speed of the locomotive or locomotives hauling the train.

P' = weight of train in tons.

P = weight of entire train (including locomotives) in tons.

Under these conditions we can write :

$$\alpha = \frac{r_0 P' + R_0}{P} = \text{specific rolling re-}$$

sistance, at low speed, of the entire train, expressed in kgr. per ton.

Further we will indicate by :

S = the frontal cross-sectional area of the train in m^2 .

β = the aerodynamic coefficient of the entire train consisting of the string of waggons and the locomotive(s).

It should be borne in mind that it is a question of a magnitude β , such that the total resistance of the air opposing the forward motion of the entire train should be indicated by the product : $\beta \times S \times v^2$ in which v is stated in metres per second. Thus for example, if K represents the aerodynamic coefficient,

(*) See Bulletin of the International Railway Congress Association, No. of March 1947, p. 139.

the speed being given in km./h., we shall have :

$$\text{whence } \beta = \frac{3.6^2 K}{100} = 0.1296 K.$$

$$\begin{aligned} \beta S v^2 &= \frac{K \times S \times V^2}{100} \\ &= \frac{K \times S \times 3.6^2 \times v^2}{100} \end{aligned}$$

If finally i represents the gradient, in mm. per metre, the differential equation should be written :

$$\begin{aligned} M \frac{dv}{dt} &= - \left\{ fQ + \alpha P + \beta S v^2 \pm iP \right\} \\ &= - \left\{ (a - bv)Q + \alpha P + \beta S v^2 \pm iP \right\} \\ &= - \left\{ aQ - bQv + \alpha P + \beta S v^2 \pm iP \right\} \\ &= - \beta S \left\{ v^2 - \frac{bQ}{\beta S} v + \frac{aQ + \alpha P \pm iP}{\beta S} \right\} \end{aligned}$$

or, substituting M by its equivalent $\frac{1000 P \gamma}{g}$:

$$\frac{1000 P \gamma}{g} \cdot \frac{dv}{dt} = - \beta S \left\{ v^2 - \frac{bQ}{\beta S} v + \frac{aQ + \alpha P \pm iP}{\beta S} \right\}$$

$$\text{whence : } \frac{dv}{dt} = - \frac{g \beta S}{1000 P \gamma} \left\{ v^2 - \frac{bQ}{\beta S} v + \frac{aQ + \alpha P \pm iP}{\beta S} \right\}$$

$$\text{whence : } dt = - \frac{1000 P \gamma}{g \beta S} \times \frac{dv}{v^2 - \frac{bQ}{\beta S} v + \frac{aQ + \alpha P \pm iP}{\beta S}}$$

or, by writing :

$$\gamma = \frac{1000 P \gamma}{g \beta S} \dots \dots \dots (6)$$

$$p = - \frac{bQ}{\beta S} \dots \dots \dots (7)$$

$$q = \frac{aQ + \alpha P \pm iP}{\beta S} \dots \dots \dots (8)$$

we get :

$$dt = - \gamma \times \frac{dv}{v^2 + pv + q} \dots \dots \dots I$$

and then $dl = v dt$

$$\text{or } dl = - \gamma \times \frac{v dv}{v^2 + pv + q} \dots \dots \dots II$$

differential equations, integrated between the limits of speed v_1 and v_2 where the linear law is represented by the equation $f = a - bv$, they (the differential equations) provide the magnitudes for the time and for the distance travelled corresponding to these speed limits.

These magnitudes are indicated by the symbols t_1 and l_1 in our previous theorem (Issue of the *Bulletin of the International Railway Congress Association* of July 1946).

They will be used in what follows. In this connection let us remember, that :

— If $\frac{p^2}{4} - q > 0$, we may write :

$$\left\{ \begin{array}{l} \Delta = \sqrt{\frac{p^2}{4} - q} \\ A = -\left(\Delta + \frac{p}{2}\right) \\ B = \Delta - \frac{p}{2} \end{array} \right.$$

— And if $\frac{p^2}{4} - q < 0$, we may write :

$$\Theta = \sqrt{q - \frac{p^2}{4}}$$

FIRST ASSUMPTION.

The coefficient of friction f between the brake blocks and the tyres varies according to a simple straight line law $f = a - bv$ from the speed $v_1 = v_n$ (describing the conditions at the start of the period under consideration) up to the stoppage of the train (speed $v_2 = 0$).

We shall have noted in our preceding theorem that integration of the differential equations I and II between the limits of the aforementioned speeds, enables us to calculate, as follows, the time T' and the distance travelled L' .

1) *Calculation of the time T' elapsed between the start of the period under consideration (characterized by the speed v_n) and the stoppage of the train.*

$$a) \text{ If } \frac{p^2}{4} - q > 0, \text{ we find } T' = \frac{\gamma}{2\Delta} \left[\log_n \frac{A}{A - v_n} - \log_n \frac{B}{B - v_n} \right]$$

$$b) \text{ If } \frac{p^2}{4} - q = 0, \text{ we find } T' = \frac{\gamma v_n}{\left(v_n + \frac{p}{2}\right) \frac{p}{2}}$$

$$c) \text{ If } \frac{p^2}{4} - q < 0, \text{ we find } T' = \frac{\gamma}{\Theta} \operatorname{arc} \operatorname{tg} \frac{\Theta v_n}{\Theta^2 + \left(v_n + \frac{p}{2}\right) \frac{p}{2}}$$

2) *Calculation of the distance L' travelled during the time T' .*

$$a) \text{ If } \frac{p^2}{4} - q > 0, L' = \frac{\gamma}{2\Delta} \left[A \log_n \frac{A}{A - v_n} - B \log_n \frac{B}{B - v_n} \right]$$

$$b) \text{ If } \frac{p^2}{4} - q = 0, L' = \gamma \log_n \frac{v_n + \frac{p}{2}}{\frac{p}{2}} - \frac{pT'}{2}$$

$$c) \text{ If } \frac{p^2}{4} - q < 0, L' = \frac{\gamma}{2} \log_n \frac{\left(v_n + \frac{p}{2}\right)^2 + \Theta^2}{\left(\frac{p}{2}\right)^2 + \Theta^2} - \frac{pT'}{2}$$

SECOND ASSUMPTION.

The coefficient of friction f between the brake shoes and the tyres of the wheels subject to braking, varies as a function of the speed and follows a hyperbolic law, the components being two linear laws, such that the speed of transition (v_0) lies between the speed v_n (initial speed of the period under consideration) and zero speed (stoppage of the train).

On this assumption, two phases are thereafter to be considered :

— a first phase, in which :

$$f = a_1 - b_1 v$$

$$\gamma = \frac{1000 P \eta}{g \beta S}$$

$$p_1 = -\frac{b_1 Q}{\beta S}$$

$$q_1 = \frac{a_1 Q + \alpha P \pm i P}{\beta S}$$

$$\text{If } \frac{p_1^2}{4} - q_1 > 0$$

$$\Delta_1 = \sqrt{\frac{p_1^2}{4} - q_1}$$

$$A_1 = -\left(\Delta_1 - \frac{p_1}{2}\right)$$

$$B_1 = \Delta_1 - \frac{p_1}{2}$$

$$\text{If } \frac{p_1^2}{4} - q_1 < 0$$

$$\Theta_1 = \sqrt{q_1 - \frac{p_1^2}{4}}$$

— a second phase, where :

$$f = a_2 - b_2 v$$

$$\gamma = \frac{1000 P \eta}{g \beta S}$$

$$p_2 = -\frac{b_2 Q}{\beta S}$$

$$q_2 = \frac{a_2 Q + \alpha P \pm i P}{\beta S}$$

$$\text{If } \frac{p_2^2}{4} - q_2 > 0$$

$$\Delta_2 = \sqrt{\frac{p_2^2}{4} - q_2}$$

$$A_2 = -\left(\Delta_2 - \frac{p_2}{2}\right)$$

$$B_2 = \Delta_2 - \frac{p_2}{2}$$

$$\text{If } \frac{p_2^2}{4} - q_2 < 0$$

$$\Theta_2 = \sqrt{q_2 - \frac{p_2^2}{4}}$$

First phase.

1) Calculation of the time t_1 elapsed from the start of the period under consideration up to the moment when the known speed of transition (v_0) is reached.

$$a) \text{ If } \frac{p_1^2}{4} - q_1 > 0, t_1 = \frac{\gamma}{2\Delta_1} \left[\log_n \frac{A_1 - v_0}{A_1 - v_n} - \log_n \frac{B_1 - v_0}{B_1 - v_n} \right]$$

$$b) \text{ If } \frac{p_1^2}{4} - q_1 = 0, t_1 = \frac{\gamma(v_n - v_0)}{\left(v_n + \frac{p_1}{2}\right)\left(v_0 + \frac{p_1}{2}\right)}$$

$$c) \text{ If } \frac{p_1^2}{4} - q_1 < 0, t_1 = \frac{\gamma}{\Theta_1} \arctg \frac{\Theta_1(v_n - v_0)}{\Theta_1^2 + \left(v_n + \frac{p_1}{2}\right)\left(v_0 + \frac{p_1}{2}\right)}$$

2) *Calculation of the distance l_1 travelled in the time t_1 .*

$$a) \text{ If } \frac{p_1^2}{4} - q_1 > 0, l_1 = \frac{\gamma}{2\Delta_1} \left[A_1 \log_n \frac{A_1 - v_0}{A_1 - v_n} - B_1 \log_n \frac{B_1 - v_0}{B_1 - v_n} \right]$$

$$b) \text{ If } \frac{p_1^2}{4} - q_1 = 0, l_1 = \gamma \log_n \frac{v_n + \frac{p_1}{2}}{v_0 + \frac{p_1}{2}} - \frac{p_1 t_1}{2}$$

$$c) \text{ If } \frac{p_1^2}{4} - q_1 < 0, l_1 = \frac{\gamma}{2} \log_n \frac{\left(v_n + \frac{p_1}{2}\right)^2 + \Theta_1^2}{\left(v_0 + \frac{p_1}{2}\right)^2 + \Theta_1^2} - \frac{p_1 t_1}{2}$$

Second phase.

1) *Calculation of the time t_2 elapsed from the moment when the known speed of transition (v_0) has been reached, up to the stoppage of the train.*

$$a) \text{ If } \frac{p_2^2}{4} - q_2 > 0, t_2 = \frac{\gamma}{2\Delta_2} \left[\log_n \frac{A_2}{A_2 - v_0} - \log_n \frac{B_2}{B_2 - v_0} \right]$$

$$b) \text{ If } \frac{p_2^2}{4} - q_2 = 0, t_2 = \frac{\gamma v_0}{\left(v_0 + \frac{p_2}{2}\right) \frac{p_2}{2}}$$

$$c) \text{ If } \frac{p_2^2}{4} - q_2 < 0, t_2 = \frac{\gamma}{\Theta_2} \arctg \frac{\Theta_2 v_0}{\Theta_2^2 + \left(v_0 + \frac{p_2}{2}\right) \frac{p_2}{2}}$$

2) *Calculation of the distance l_2 travelled in the time t_2 .*

$$a) \text{ If } \frac{p_2^2}{4} - q_2 > 0, l_2 = \frac{\gamma}{2\Delta_2} \left[A_2 \log_n \frac{A_2}{A_2 - v_0} - B_2 \log_n \frac{B_2}{B_2 - v_0} \right]$$

$$b) \text{ If } \frac{p_2^2}{4} - q_2 = 0, l_2 = \gamma \log_n \frac{v_0 + \frac{p_2}{2}}{\frac{p_2}{2}} - \frac{p_2 t_2}{2}$$

$$c) \text{ If } \frac{p_2^2}{4} - q_2 < 0, l_2 = \frac{\gamma}{2} \log_n \frac{\left(v_0 + \frac{p_2}{2}\right)^2 + \Theta_2^2}{\left(\frac{p_2}{2}\right)^2 + \Theta_2^2} - \frac{p_2 t_2}{2}$$

3) Finally, then we get :

$$T' = t_1 + t_2$$

$$L' = l_1 + l_2$$

B. SECOND CASE.

The wheels of the different braked waggons in the train (as also of the locomotives hauling the latter) are locked and skid from the start of the period under consideration (distinguished by the speed $v_1 = v_n$) until the stoppage of the train ($v_2 = 0$).

Let :

P_0 = the weight in tons of all the braked waggons and locomotives. This weight will thus correspond to that of the locked vehicles skidding on the track.

$P - P_0$ = the weight in tons of all the unbraked vehicles, P being the total weight of the train (including locomotives). This weight therefore corresponds to that part of the train which continues to roll on the track.

M = the total mass of the entire train, it being noted that it is only the mass weighing $P - P_0$ not braked which should be affected by the multiplier γ so that in this case :

$$M = \frac{1000 P_0}{g} + \frac{1000(P - P_0) \gamma}{g}$$

$$= \frac{1000[P_0 + (P - P_0)\gamma]}{g}$$

$f' = a' - b'v$ = skidding coefficient of the tyres on the rails, varying between the speed limits $v_1 = v_n$ and $v_2 = 0$.

Under these conditions and the case under consideration, the differential equation governing the motion may be written :

$$M \frac{dv}{dt} = - \{ 1000 f' P_0 + (P - P_0) r_0 + \beta S v^2 \pm i P \}$$

the values of r_0 , of β and of S being indicated above (*).

Let us now replace f' by its equivalent $a' - b'v$, and then we get :

$$M \frac{dv}{dt} = - \{ 1000(a' - b'v)P_0 + (P - P_0)r_0 + \beta S v^2 \pm i P \}$$

$$= - \{ 1000 a' P_0 - 1000 b' P_0 v + (P - P_0)r_0 + \beta S v^2 \pm i P \}$$

$$= - \beta S \left\{ v^2 - \frac{1000 b' P_0}{\beta S} v + \frac{1000 a' P_0 + (P - P_0)r_0 \pm i P}{\beta S} \right\}$$

$$\text{whence : } \frac{dv}{dt} = - \frac{\beta S}{M} \left\{ v^2 - \frac{1000 b' P_0}{\beta S} v + \frac{1000 a' P_0 + (P - P_0)r_0 \pm i P}{\beta S} \right\}$$

$$= - \frac{g \beta S}{1000[P_0 + (P - P_0)\gamma]} \left\{ v^2 - \frac{1000 b' P_0}{\beta S} v + \frac{1000 a' P_0 + (P - P_0)r_0 \pm i P}{\beta S} \right\}$$

(*) See page 201.

$$\text{whence: } dt = - \frac{1000[P_0 + (P - P_0)\eta]}{g\beta S}$$

$$\times \left\{ v^2 - \frac{1000 b'P_0}{\beta S} v + \frac{1000 a'P_0 + (P - P_0)r_0 \pm iP}{\beta S} \right\}$$

or, by writing :

$$\gamma' = \frac{1000[P_0 + (P - P_0)\eta]}{g\beta S} \dots \dots \dots (9)$$

$$p' = - \frac{1000 b'P_0}{\beta S} \dots \dots \dots (10)$$

$$q' = \frac{1000 a'P_0 + (P - P_0)r_0 \pm iP}{\beta S} \dots \dots \dots (11)$$

we get :

$$dt = - \gamma' \times \frac{dv}{v^2 + p'v + q'}$$

and, consequently :

$$dl = v dt$$

or :

$$dl = - \gamma' \times \frac{v dv}{v^2 + p'v + q'}$$

differential equations of the same form as (I) and (II).

FIRST ASSUMPTION.

The coefficient of sliding friction f' of the tyres on the rails varies according to the same linear law $f' = a' - b'v$ (suitably chosen) from the speed $v_1 = v_n$ up to stoppage of the train ($v_0 = 0$).

The magnitudes T' and L' are found as indicated above (first case, first assumption), at the same time taking into account the relationship $\gamma' = (9)$, $p' = (10)$, $q' = (11)$ shown above.

SECOND ASSUMPTION.

The coefficient of sliding friction f' of the tyres on the rails varies according to a first linear law $f_1' = a_1' - b_1'v$ from the speed $v_1 = v_n$ up to the speed of transition v_0 , and according to a second linear law $f_2' = a_2' - b_2'v$ from the same transition v_0 down to the speed $v_2 = 0$ (stoppage of the train).

Under these conditions, we shall have, as above (first case, second assumption):

$$\left\{ \begin{array}{l} t_1 \text{ and } t_2, \text{ whence } T' = t_1 + t_2 \\ l_1 \text{ and } l_2, \text{ whence } L' = l_1 + l_2 \end{array} \right.$$

At the same time taking into account that :

— For the first phase, from v_n to v_0 :

$$\gamma' = \frac{1000[P_0 + (P - P_0)\eta]}{g\beta S} = (9)$$

$$p_1' = - \frac{1000 b_1' P_0}{\beta S} \dots \dots \dots (12)$$

$$q_1' = \frac{1000 a_1' P_0 + (P - P_0)r_0 \pm iP}{\beta S} \dots \dots \dots (13)$$

— For the second phase from v_0 to stoppage of the train :

$$\gamma' = \frac{1000[P_0 + (P - P_0)\eta]}{g\beta S} = (9)$$

$$p_2' = - \frac{1000 b_2' P_0}{\beta S} \dots \dots \dots (14)$$

$$q_2' = \frac{1000 a_2' P_0 + (P - P_0)r_0 \pm iP}{\beta S} \dots \dots \dots (15)$$

Note. — If the speed v_n is low enough (e.g. 4 to 5 m./sec.), one can leave out of account the resistance of the air, a resistance which moreover is negligible at such low speeds. In this case the differential equations of the motion become simplified and give the following results:

A. Case where the train continues to run without skidding of wheels on the braked waggons.

The equation for the motion then becomes :

$$\begin{aligned} M \frac{dv}{dt} &= - \{ fQ + \alpha P \pm iP \} \\ &= - \{ (a - bv)Q + \alpha P \pm iP \} \\ &= - \{ aQ - bQv + \alpha P \pm iP \} \\ &= - \{ aQ + \alpha P \pm iP - bQv \} \\ &= - bQ \left\{ \frac{aQ + \alpha P \pm iP}{bQ} - v \right\} \end{aligned}$$

or, substituting M by its equivalent $\frac{1000 P \eta}{g}$:

$$\frac{1000 P \eta}{g} \cdot \frac{dv}{dt} = - bQ \left\{ \frac{aQ + \alpha P \pm iP}{bQ} - v \right\}$$

$$\text{whence } \frac{dv}{dt} = - \frac{gbQ}{1000 P \eta} \left\{ \frac{aQ + \alpha P \pm iP}{bQ} - v \right\}$$

$$\text{whence } dt = - \frac{1000 P \eta}{gbQ} \times \frac{dv}{\frac{aQ + \alpha P \pm iP}{bQ} - v}$$

By writing :

$$\begin{cases} k = \frac{1000 P \eta}{gbQ} \\ s = \frac{aQ + \alpha P \pm iP}{bQ} \end{cases}$$

we then have :

$$dt = -k \times \frac{dv}{s - v}$$

and consequently $dl = vdt$

$$\text{or : } dl = -k \times \frac{v dv}{s - v}$$

Integration of these differential equations between the speed limits v_1 and v_2 gives us :

$$t = -k \int_{v_1}^{v_2} \frac{dv}{s - v}$$

$$= k \log_n \frac{s - v_2}{s - v_1}$$

$$l = -k \int_{v_1}^{v_2} \frac{v dv}{s - v}$$

$$= ks \log_n \frac{s - v_2}{s - v_1} - k(v_1 - v_2)$$

$$= st - k(v_1 - v_2)$$

FIRST ASSUMPTION.

$f = a - bv$ from the speed v_n down to the stoppage of the train.

$$\begin{cases} v_1 = v_n \\ v_2 = \text{zero (stoppage of the train).} \end{cases}$$

$$\begin{cases} k = \frac{1000 P \eta}{gbQ} \\ s = \frac{aQ + \alpha P \pm iP}{bQ} \end{cases}$$

$$\begin{cases} T' = k \log_n \frac{s}{s - v_n} \\ L' = sT' - k.v_n \end{cases}$$

SECOND ASSUMPTION.

$$\begin{cases} f = a_1 - b_1 v \text{ from the speed } v_n \text{ down to the speed of transition } v_0. \\ f = a_2 - b_2 v \text{ from this last speed down to the stoppage of the train.} \end{cases}$$

First phase.

$$\begin{cases} f = a_1 - b_1 v \\ v_1 = v_n \\ v_2 = v_0 \end{cases}$$

$$\begin{cases} k_1 = \frac{1000 P \eta}{gb_1 Q} \\ s_1 = \frac{a_1 Q + \alpha P \pm iP}{b_1 Q} \end{cases}$$

$$\begin{cases} t_1 = k_1 \log_n \frac{s_1 - v_0}{s_1 - v_n} \\ l_1 = s_1 t_1 - k_1(v_n - v_0) \end{cases}$$

Second phase.

$$\begin{cases} f = a_2 - b_2 v \\ v_1 = v_0 \\ v_2 = \text{zero (stoppage of train).} \end{cases}$$

$$\begin{cases} k_2 = \frac{1000 P \eta}{gb_2 Q} \\ s_2 = \frac{a_2 Q + \alpha P \pm iP}{b_2 Q} \end{cases}$$

$$\begin{cases} t_2 = k_2 \log_n \frac{s_2}{s_2 - v_0} \\ l_2 = s_2 t_2 - k_2 v_0 \end{cases}$$

whence

$$\begin{cases} T' = t_1 + t_2 \\ L' = l_1 + l_2 \end{cases}$$

B. Case where the wheels of various braked waggons are skidded and slide from the commencement of this period until the train comes to rest.

The differential equation for this motion will be :

$$\begin{aligned} M \frac{dv}{dt} &= - \{ 1000 f' P_0 + (P - P_0) r_0 \pm i P \} \\ &= - \{ 1000 (a' - b'v) P_0 + (P - P_0) r_0 \pm i P \} \\ &= - \{ 1000 a' P_0 - 1000 b' P_0 v + (P - P_0) r_0 \pm i P \} \\ &= - 1000 b' P_0 \left\{ \frac{1000 a' P_0 + (P - P_0) r_0 \pm i P}{1000 b' P_0} - v \right\} \end{aligned}$$

whence $\frac{dv}{dt} = - \frac{1000 b' P_0}{M} \left\{ \frac{1000 a' P_0 + (P - P_0) r_0 \pm i P}{1000 b' P_0} - v \right\}$

or, by replacing M by its value $\frac{1000 [P_0 + (P - P_0) \eta]}{g}$

$$\begin{aligned} \frac{dv}{dt} &= - \frac{1000 g b' P_0}{1000 [P_0 + (P - P_0) \eta]} \left\{ \frac{1000 a' P_0 + (P - P_0) r_0 \pm i P}{1000 b' P_0} - v \right\} \\ &= - \frac{g b' P_0}{P_0 + (P - P_0) \eta} \left\{ \frac{1000 a' P_0 + (P - P_0) r_0 \pm i P}{1000 b' P_0} - v \right\} \end{aligned}$$

whence $dt = - \frac{P_0 + (P - P_0) \eta}{g b' P_0} \times \frac{dv}{\left\{ \frac{1000 a' P_0 + (P - P_0) r_0 \pm i P}{1000 b' P_0} - v \right\}}$

or, by writing :

$$k' = \frac{P_0 + (P - P_0) \eta}{g b' P_0}$$

$$s' = \frac{1000 a' P_0 + (P - P_0) r_0 \pm i P}{1000 b' P_0}$$

we find again :

$$dt = - k' \times \frac{dv}{s' - v}$$

and, consequently :

$$\begin{aligned} dl &= v dt \\ &= - k' \times \frac{v dv}{s' - v} \end{aligned}$$

so that

$$\begin{aligned} t &= k' \log_n \frac{s' - v_2}{s' - v_1} \\ l &= s' t - k' (v_1 - v_2) \end{aligned}$$

FIRST ASSUMPTION.

$$\left\{ \begin{array}{l} f' = a' - b'v \text{ from the speed } v_n \text{ down} \\ \text{to the stoppage of the train.} \\ v_1 = v_n \\ v_2 = \text{zero (stoppage of the train).} \\ T' = k' \log_n \frac{s'}{s' - v_n} \\ L' = s' T' - k' v_n \end{array} \right.$$

with the above values of k' and of s' .

SECOND ASSUMPTION.

$$\left\{ \begin{array}{l} f' = a_1' - b_1'v \text{ of } v_n \text{ to } v_0 \\ f' = a_2' - b_2'v \text{ of } v_0 \text{ to zero (stop-} \\ \text{page of the train).} \end{array} \right.$$

First phase.

$$\left\{ \begin{array}{l} f' = a_1' - b_1'v \\ v_1 = v_n \\ v_2 = v_0 \end{array} \right.$$

$$\left\{ \begin{aligned} k_1' &= \frac{P_0 + (P - P_0)\eta}{gb_1'P_0} \\ s_1' &= \frac{1000 a_1'P_0 + (P - P_0)r_0 \pm iP}{1000 b_1'P_0} \\ t_1 &= k_1' \log_n \frac{s_1' - v_0}{s_1' - v_n} \\ l_1 &= s_1't_1 - k_1'(v_n - v_0) \end{aligned} \right.$$

Second phase.

$$\left\{ \begin{aligned} f' &= a_2' - b_2'v \\ v_1 &= v_0 \\ v_2 &= \text{zero (stoppage of the train).} \\ k_2' &= \frac{P_0 + (P - P_0)\eta}{gb_2'P_0} \\ s_2' &= \frac{1000 a_2'P_0 + (P - P_0)r_0 \pm iP}{1000 b_2'P_0} \\ t_2 &= k_2' \log_n \frac{s_2' - v_0}{s_2' - v_0} \\ l_2 &= s_2't_2 - k_2'v_0 \end{aligned} \right.$$

Whence $T' = t_1 + t_2$ and $L' = l_1 + l_2$

NUMERICAL EXAMPLE.

A. Data for the calculation.

P = weight of entire train = 1312 tons.

P' = weight of the train of waggons only (*) = 1200 tons.

P'' = weight of the locomotive (**) = 112 tons.

P_0 = weight of that part of the train, fitted with brakes = 412 tons.

$P - P_0$ = weight of part of the train without brakes = 900 tons.

η = coefficient for gross weight of mass = 1.08.

Q = force exerted by a maximum application of the brakes on the tyres of

the whole of the vehicles provided with brakes in the train = 200 000 kgr.

T = time needed to charge the brake cylinders on the vehicles fitted with brakes in the train = 55 seconds.

n = the numerical exponent characterising the value of the function $q = \Psi(t)$ taken as, say 2.5.

v_1 = the speed at the moment of starting to brake = 15 m. per sec., say $3.6 \times 15 = 54$ km. per hour.

β = aerodynamic coefficient for the whole train = say 0.8, the speed of the train being given in m./sec. so that

$$0.8Sv^2 = \frac{6.2 Sv^2}{100}.$$

S = the surface area of the front of the train = 12 m².

i = the gradient of that section of the line travelled over by the train during the period of braking = *gradient* of 5mm. per metre = - 5.

B. Preliminary observations.

In the numerical example dealt with below, in connection with the choice of the coefficients of friction $f = F(v)$ and $f' = F_1(v)$ we have been guided exclusively by Doyen's laws, i.e.:

1) As regards the *frictional coefficient* $f = F(v)$ between the brake blocks and the tyres, for the case of a *purely rolling motion* of the braked wheels in the train, during the *period of charging of the brake cylinders* and on the assumption of a *purely rolling motion* of the same parts of the train during the *period of braking at constant pressure*:

we have: $f = 0.27 - 0.0072v$

2) As regards the *coefficient of sliding friction* $f' = F_1(v)$ between the tyres and the rails on the assumption of the

(*) Assumed that train is made up of 30 % empty waggons and 70 % loaded.

(**) Type 81 of the S.N.C.B.

sliding of the part of the train under consideration, during the *period of constant brake pressure* :

$$f' = 0.095 - 0.0024 v$$

up to the transition speed $v_0 = 3.23$ m./sec.

$$f' = 0.25 - 0.0054 v$$

from the same speed of transition v_0 up to the stoppage of the train.

C. Results of the calculations.

I. Period of charging the brake cylinders.

1) *Calculation by a first approximation of the speed v_n characterizing the end of the period in question.*

The relation :

$$v_B' = v_A - \frac{g.T}{1000.P.\gamma} \left\{ \frac{nf_A Q}{n+1} + r_A P' + R_A - iP \right\}$$

which amounts to :

$$\begin{aligned} v_B' &= 15 - \frac{9.81 \times 55}{1000 \times 1312 \times 1.08} \left\{ 23143 + 4716 + 1106 - 6560 \right\} \\ &= 15 - \frac{9.81 \times 55 \times 22405}{1000 \times 1312 \times 1.08} \\ &= 15 - 8.54 \\ &= 6.460 \text{ metres per second (or say 23.2 km./h.).} \end{aligned}$$

2) *Calculation by a second approximation of the speed v_B .*

The relation :

$$v_B = v_A - \frac{g.T}{1000.P.\gamma} \left\{ \frac{nf_A Q}{2(n+2)} + \frac{n(n+3)f_B Q}{2(n+1)(n+2)} + \frac{1}{2}(r_A + r_B)P' + \frac{1}{2}(R_A + R_B) - iP \right\}$$

in which :

v_B' = the value approximating to the speed v_n which has to be found;

v_A = speed of the train at commencement of braking ;

= 15 metres per second;

g = acceleration of gravity;

= 9.81 m./sec²;

f_A = coefficient of friction of the brake blocks on the tyres, corresponding to the speed v_A of the train at the commencement of braking (15 m./sec. = 54 km./h.);

= $0.27 - 0.0072 \times 15$

= 0.162;

r_A = specific resistance of the string of waggons corresponding to the same speed;

= 3.93 kgr./ton (see Appendix II);

R_A = total resistance of the locomotive corresponding likewise to the same speed;

= 1 106 kgr. (see Appendix I)

in which :

$$\begin{cases} f_A = 0.27 - 0.0072 \times 15 = 0.162 \\ f_B = 0.27 - 0.0072 \times 6.460 = 0.2235 \end{cases}$$

$$\begin{cases} r_A = 3.93 \text{ kgr. per ton of the string of waggons at the speed } v_A = 15 \text{ m./sec. or } 54 \text{ km./h.} \\ R_A = 1106 \text{ kgr. (locomotive), at the speed } v_A = 15 \text{ m./sec. or } 54 \text{ km./h.} \end{cases}$$

$$\begin{cases} r_B = 2.21 \text{ kgr. per ton of the string of waggons, at the speed } v_B' = 6.46 \text{ m./sec. or } 23 \text{ km./h.} \\ R_B = 722 \text{ kgr. (locomotive), at the speed } v_B' = 6.46 \text{ m./sec. or } 23 \text{ km./h.} \end{cases}$$

amounts to :

$$\begin{aligned} v_B &= 15 - \frac{9.81 \times 55}{1000 \times 1312 \times 1.08} \left\{ 9000 + 19512 + 3684 + 919 - 6560 \right\} \\ &= 15 - \frac{9.81 \times 55 \times 26555}{1000 \times 1312 \times 1.08} \\ &= 15 - 10.110 \\ &= 4.890 \text{ metres per second, or say } 17.6 \text{ km./h.} \end{aligned}$$

3) Calculation of the distance travelled L.

The relation :

$$L = v_A T - \frac{gT^2}{1000 P_n} \left\{ \frac{nf_A Q}{3(n+3)} + \frac{n(n+5)f_B Q}{6(n+2)(n+3)} + \frac{1}{3}r_A P' + \frac{1}{6}r_B P' + \frac{1}{3}R_A + \frac{1}{6}R_B - \frac{1}{2}P \right\}$$

gives the value :

$$\begin{aligned} L &= 15 \times 55 - \frac{9.81 \times 55^2}{1000 \times 1312 \times 1.08} \left\{ 4909 + 5644 + 1572 + 442 \right. \\ &\quad \left. + 369 + 120 - 3280 \right\} \\ &= 825 - \frac{9.81 \times 55^2 \times 9776}{1000 \times 1312 \times 1.08} \\ &= 825 - 205 \\ &= 620 \text{ metres.} \end{aligned}$$

II. Period of braking at constant pressure.

A. Case when the braked portion of the train, not being skidded, continues to run until it comes to rest :

The Appendices I and II give us :

$$r_0 = 1.82 \text{ kgr. per ton of the string of waggons.}$$

$R_0 = 586$ kgr. for the locomotive,

$$\text{whence } \alpha = \frac{r_0 P' + R_0}{P} = \frac{(1.82 \times 1200) + 586}{1312} = 2.111 \text{ kgr. per ton of train.}$$

Under these conditions, and taking account of the values :

$$\begin{cases} a = 0.27 \\ b = 0.0027 \end{cases}$$

we find :

1) *Taking into account the resistance of the air :*

$$\begin{aligned} \gamma &= \frac{1000 P \gamma}{g \beta S} \\ &= \frac{1000 \times 1312 \times 1.08}{9.81 \times 0.80 \times 12} \\ &= 15046 \end{aligned}$$

$$\begin{aligned} p &= - \frac{bQ}{\beta S} \\ &= - \frac{0.0072 \times 200000}{0.80 \times 12} \\ &= - 150 \end{aligned}$$

$$\begin{aligned} q &= \frac{aQ + \alpha P - iP}{\beta S} \\ &= \frac{(0.27 \times 200000) + (2.111 \times 1312) - (5 \times 1312)}{0.80 \times 12} \\ &= 5230 \end{aligned}$$

$$\Delta = \sqrt{\frac{p^2}{4} - q} = \sqrt{5625 - 5230} = 19.874$$

$$\begin{aligned} A &= - \left(\Delta + \frac{p}{2} \right) = - \left(19.874 - \frac{150}{2} \right) \\ &= - 19.874 + 75 \\ &= 55.126 \end{aligned}$$

$$\begin{aligned} B &= \Delta - \frac{p}{2} = 19.874 - \left(- \frac{150}{2} \right) \\ &= 19.874 + 75 \\ &= 94.874 \end{aligned}$$

whence :

$$\begin{aligned}
 T' &= \frac{\gamma \times 2.303}{2\Delta} \left[\log \frac{A}{A - v_B} - \log \frac{B}{B - v_B} \right] \\
 &= \frac{15046 \times 2.303}{2 \times 19.874} \left[\log \frac{55.126}{55.126 - 4.89} - \log \frac{94.874}{94.874 - 4.89} \right] \\
 &= 871.8 \left[\log \frac{55.126}{50.236} - \log \frac{94.874}{89.984} \right] \\
 &= 871.8 [0.0403414 - 0.0229819] \\
 &= 871.8 \times 0.0173595 \\
 &= 15.13401210, \text{ or } \mathbf{15.134 \text{ seconds.}}
 \end{aligned}$$

$$\begin{aligned}
 L' &= \frac{\gamma \times 2.303}{2\Delta} \left[A \log \frac{A}{A - v_B} - B \log \frac{B}{B - v_B} \right] \\
 &= 871.8 [55.126 \times 0.0403414 - 94.874 \times 0.0229819] \\
 &= 871.8 [2.2238600164 - 2.1803847806] \\
 &= 871.8 \times 0.0434752358 \\
 &= 37.90171057044, \text{ or } \mathbf{37.902 \text{ metres.}}
 \end{aligned}$$

2) *Neglecting the resistance of the air :*

$$\begin{aligned}
 k &= \frac{1000 P\eta}{gbQ} \\
 &= \frac{1000 \times 1312 \times 1.08}{9.81 \times 0.0072 \times 200000} \\
 &= \frac{1416960}{14126.4} \\
 &= 100.3 \\
 s &= \frac{aQ + \alpha P - iP}{b.Q} \\
 &= \frac{(0.27 \times 200000) + (2.111 \times 1312) - (5 \times 1312)}{0.0072 \times 200000} \\
 &= \frac{54000 + 2769.632 - 6560}{1440} \\
 &= \frac{50209.632}{1440} \\
 &= 34.868
 \end{aligned}$$

$$\begin{aligned}
 T' &= 2.303 \times k \times \log \frac{s}{s - v_n} \\
 &= 2.303 \times 100.3 \times \log \frac{34.868}{34.868 - 4.89} \\
 &= 2.309909 \times \log \frac{34.868}{29.978} \\
 &= 2.309909 \times 0.0656243 \\
 &= 15.15861611887, \text{ or } \mathbf{15.159 \text{ sec.}} \\
 L' &= sT' - k \times v_n \\
 &= 34.868 \times 15.159 - 100.3 \times 4.89 \\
 &= 528.564 - 490.467 \\
 &= \mathbf{38.097 \text{ metres.}}
 \end{aligned}$$

Conclusion :

It will be seen that the effect of the resistance of air is negligible at the speeds in question, as will be seen from the following table :

Time/Distance.	Resistance of air taken into account.	Resistance of air neglected.
T' seconds	15.134	15.159
L' metres	37.902	38.097

$$\begin{aligned}
 &= \frac{(1000 \times 0.095 \times 412) + (900 \times 1.82) + (5 \times 1312)}{1000 \times 0.0024 \times 412} \\
 &= \frac{34218}{988.8} \\
 &= 34.605 \\
 \text{Whence :} \\
 t_1 &= 2.303 k_1' \log \frac{s_1' - v_0}{s_1' - v_n} \\
 &= 2.303 \times 142.68 \times \log \frac{34.605 - 3.23}{34.605 - 4.89} \\
 &= 328.592 \times \log \frac{31.37}{29.71} \\
 &= 328.592 \times 0.0236118 \\
 &= 7.75864853856, \text{ or } \mathbf{7.758 \text{ seconds.}} \\
 l_1 &= s_1' t_1 - k_1' (v_n - v_0) \\
 &= 34.605 \times 7.758 - 142.68 \\
 &\quad \times (4.89 - 3.23)
 \end{aligned}$$

In view of the above, we shall decide to neglect the effect of the resistance of the air, in the following calculations.

B. Case where the braked portion of the train has its wheels locked and slides along the rails from the end of the cylinder charging period until the train comes to rest.

We should remember that in this case r_0 = the specific resistance to rolling of the unbraked portion of the train = 1.82 kgr. per ton (see Appendix II).

First phase.

$$v_n = 4.89 \text{ m./sec.}$$

$$v_0 = 3.23 \text{ m./sec.}$$

$$f' = 0.095 - 0.0024 v$$

$$\left\{ \begin{array}{l} a_1' = 0.095 \\ b_1' = 0.0024 \end{array} \right.$$

$$b_1' = 0.0024$$

$$k_1' = \frac{P_0 + (P - P_0)\eta}{gb_1'P_0}$$

$$= \frac{412 + 900 \times 1.08}{9.81 \times 0.0024 \times 412}$$

$$= \frac{1384}{9.7}$$

$$= 142.68$$

$$s_1' = \frac{1000 a_1' P_0 + (P - P_0)r_0 - iP}{1000 b_1' P_0}$$

$$= 268.46559 - 142.68 \times 1.66$$

$$= 268.46559 - 236.8488$$

$$= 31.61679, \text{ or } \mathbf{31.617 \text{ metres.}}$$

Second phase.

$$v_0 = 3.23 \text{ m./sec.}$$

$$f' = 0.25 - 0.0504v$$

$$\begin{cases} a_2' = 0.25 \\ b_2' = 0.0504 \end{cases}$$

$$k_2' = \frac{P_0 + (P - P_0)\eta}{gb_2'P_0}$$

$$= \frac{412 + 900 \times 1.08}{9.81 \times 0.0504 \times 412}$$

$$= \frac{1384}{203.7}$$

$$= 6.794$$

$$s_2' = \frac{1000 a_2'P_0 + (P - P_0)r_0 - iP}{1000 b_2'P_0}$$

$$= \frac{103000 + 1638 - 6560}{20764.8}$$

$$= \frac{98078}{20764.8}$$

$$= 4.723$$

Whence :

$$t_2 = 2.303 k_2' \log \frac{s_2'}{s_2' - v_0}$$

$$= 2.303 \times 6.794 \times \log \frac{4.723}{4.723 - 3.23}$$

$$= 15.646582 \times \log \frac{4.723}{1.493}$$

$$= 15.646582 \times 0.5001581$$

$$= 7.8257647246142, \text{ or } \mathbf{7.826 \text{ seconds.}}$$

$$l_2 = s_2't_2 - k_2'v_0$$

$$= 4.723 \times 7.826 - 6.794 \times 3.23$$

$$= 36.962198 - 21.94462$$

$$= 15.017578, \text{ or } \mathbf{15.017 \text{ metres.}}$$

So that :

$$T' = t_1 + t_2 = 7 \text{ sec. } 758 + 7 \text{ sec. } 826 = \mathbf{15 \text{ sec. } 584.}$$

$$L' = l_1 + l_2 = 31 \text{ m. } 617 + 15 \text{ m. } 017 = \mathbf{46 \text{ m. } 634.}$$

Summary.

<i>Periods.</i>	<i>Seconds.</i>	<i>Metres.</i>	<i>Seconds.</i>	<i>Metres.</i>
<i>First period</i>	55	620	55	620
<i>Second period :</i>				
<i>wheels turning</i>	15.134	37.902
<i>wheels skidded</i>	15.584	46.634
Total braking effect	70.134	657.902	70.584	666.634

Total resistance of locomotives belonging to the Belgian National Railways used

	Types						
	000		00000	0000			
	41	44	40	72	77	80	8
	90.600	87.850	117.040	88.775	82.150	90.075	112
Total weight (including tender) in metric tonnes.	52.200	49.450	49.850	52.900	45.050	57.270	67
Adhesive weight in metric tonnes.							
Speed in km/h.	Total resistance						
0	407	389	460	461	349	482	5
1	411	393	464	466	352	487	5
2	416	398	469	471	355	492	5
3	420	402	473	477	358	497	6
4	425	407	478	482	361	502	6
5	429	412	482	488	364	507	6
6	434	416	487	493	367	512	6
7	438	421	491	499	370	517	6
8	443	425	496	504	373	522	6
9	447	430	500	510	376	527	6
10	452	434	505	516	379	532	6
1	457	439	509	522	383	538	6
2	462	444	514	529	386	544	6
3	467	449	519	535	390	550	6
4	472	454	523	542	393	556	6
5	477	459	528	549	397	562	6
6	482	464	532	556	401	568	6
7	487	469	537	563	403	574	6
8	492	474	542	570	408	580	6
9	497	479	547	577	411	586	6
20	502	484	552	584	415	593	6
1	508	490	559	593	420	601	7
2	514	496	565	603	425	609	7
3	520	503	572	612	430	617	7
4	527	509	579	622	435	626	7
5	533	515	586	631	440	634	7
6	540	522	592	641	445	642	7
7	546	528	599	651	450	650	7
8	553	535	605	661	455	659	7
9	559	541	612	671	460	667	7
30	566	548	617	681	465	676	7
1	575	557	625	693	471	686	7
2	584	566	633	705	477	697	8
3	593	575	641	717	484	708	8
4	602	584	649	729	491	719	8
5	611	593	658	741	497	730	8
6	620	611	666	753	504	741	8
7	629	620	674	765	510	752	8
8	638	629	683	777	517	763	8
9	647	639	691	790	523	774	8
40	657	650	700	805	530	785	8
1	668	661	710	821	538	799	9
2	679	672	720	838	547	813	9
3	690	683	730	855	555	827	9
4	701	694	740	872	564	841	9
5	712	705	750	889	572	855	9
6	723	716	760	906	580	869	9
7	734	727	770	923	588	883	9
8	745	738	780	940	597	897	10
9	756	749	790	957	605	911	10
50	767	749	800	974	614	926	10
1	781	763	812	997	625	945	10
2	795	777	825	1 021	637	964	10
3	809	791	837	1 045	648	983	10
4	823	805	850	1 069	659	1 002	11
5	837	819	863	1 093	670	1 021	11

ains (dual purpose locomotives and special goods locomotives).

omotives.

○○○○○						○○○○○
31	33	35	38	48	76	90
0.600	138.600	163.200	138.500	135.560	110.139	114.890
1.800	75.100	93.200	75.200	75.700	61.820	71.490

kilogrammes.

711	985	407	685	551	532	662
715	989	411	689	555	537	667
719	994	416	694	561	542	672
724	999	420	698	565	546	677
728	1 003	425	703	571	551	682
733	1 008	429	707	576	555	687
737	1 012	434	711	581	560	692
742	1 017	438	716	587	564	697
746	1 021	443	720	593	568	701
751	1 026	447	725	598	574	706
756	1 030	452	730	603	578	711
760	1 035	457	734	610	584	717
765	1 039	462	739	616	589	723
770	1 044	467	744	622	594	729
775	1 049	472	749	628	600	735
780	1 054	477	754	634	605	741
785	1 059	482	759	639	611	747
790	1 064	487	764	647	616	753
795	1 069	492	769	653	622	759
800	1 074	497	774	658	627	765
805	1 079	502	779	665	634	771
811	1 085	508	785	673	641	778
818	1 092	514	792	680	648	786
825	1 098	520	798	687	655	793
831	1 105	527	805	693	664	801
838	1 111	533	811	701	671	808
844	1 118	540	818	709	678	816
850	1 124	546	824	716	686	823
857	1 131	553	831	723	694	831
864	1 138	559	838	731	701	839
871	1 145	566	845	737	709	848
880	1 154	575	854	745	718	858
889	1 163	584	863	752	728	868
898	1 172	593	872	760	738	878
907	1 181	602	881	767	748	888
916	1 190	611	890	775	758	898
925	1 199	620	899	782	768	908
934	1 208	629	908	789	778	918
943	1 217	638	917	796	788	929
952	1 226	647	926	804	798	939
961	1 235	657	935	811	807	950
972	1 246	668	946	818	820	962
983	1 257	679	957	826	833	975
994	1 268	690	968	834	847	987
1 005	1 279	701	979	840	860	1 000
1 016	1 290	712	990	847	873	1 012
1 027	1 301	723	1 001	855	884	1 025
1 038	1 312	734	1 012	863	897	1 037
1 049	1 323	745	1 023	870	910	1 050
1 060	1 334	756	1 034	878	923	1 062
1 071	1 345	767	1 045	884	936	1 075
1 085	1 359	781	1 058	893	954	1 092
1 099	1 373	795	1 068	904	971	1 110
1 113	1 387	809	1 080	914	988	1 127
1 127	1 401	823	1 091	924	1 005	1 145
1 141	1 415	837	1 105	933	1 023	1 162

APPENDIX II.

Specific resistance of goods trains (expressed in kilogrammes per tonne of weight of the stock).

Speed km./h.	Goods trains.										
	As made up with empty waggons.										
	0 %	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	100 %
0	1.59	1.65	1.73	1.82	1.92	2.03	2.18	2.40	2.66	2.99	3.46
1	1.59	1.65	1.73	1.82	1.92	2.03	2.18	2.40	2.66	2.99	3.46
2	1.59	1.65	1.73	1.82	1.92	2.03	2.19	2.41	2.67	3.00	3.47
3	1.59	1.65	1.73	1.82	1.92	2.03	2.19	2.41	2.68	3.00	3.48
4	1.60	1.66	1.74	1.83	1.93	2.04	2.20	2.42	2.68	3.01	3.49
5	1.60	1.66	1.74	1.83	1.93	2.04	2.20	2.42	2.69	3.02	3.50
6	1.61	1.67	1.75	1.84	1.94	2.05	2.21	2.43	2.70	3.04	3.52
7	1.62	1.68	1.76	1.85	1.95	2.06	2.22	2.45	2.72	3.06	3.54
8	1.63	1.69	1.77	1.87	1.97	2.08	2.24	2.47	2.74	3.08	3.57
9	1.64	1.70	1.78	1.88	1.98	2.09	2.26	2.48	2.76	3.10	3.59
10	1.65	1.71	1.79	1.89	1.99	2.11	2.27	2.50	2.78	3.12	3.61
11	1.67	1.73	1.81	1.91	2.01	2.13	2.29	2.52	2.80	3.15	3.65
12	1.68	1.74	1.83	1.93	2.03	2.15	2.32	2.55	2.83	3.18	3.68
13	1.70	1.76	1.85	1.95	2.05	2.18	2.34	2.57	2.85	3.21	3.72
14	1.71	1.78	1.87	1.97	2.08	2.20	2.36	2.60	2.88	3.24	3.76
15	1.73	1.80	1.89	1.99	2.10	2.22	2.39	2.63	2.91	3.27	3.79
16	1.75	1.82	1.91	2.01	2.12	2.25	2.42	2.66	2.95	3.31	3.84
17	1.78	1.84	1.93	2.03	2.15	2.28	2.45	2.70	2.99	3.36	3.89
18	1.80	1.86	1.95	2.06	2.18	2.30	2.48	2.73	3.03	3.40	3.94
19	1.82	1.89	1.97	2.08	2.20	2.33	2.51	2.76	3.07	3.44	3.99
20	1.84	1.91	2.00	2.11	2.23	2.36	2.54	2.80	3.11	3.49	4.04
21	1.87	1.94	2.03	2.14	2.27	2.39	2.58	2.84	3.16	3.54	4.10
22	1.90	1.97	2.06	2.18	2.30	2.43	2.62	2.88	3.20	3.60	4.17
23	1.92	2.00	2.09	2.21	2.33	2.47	2.66	2.93	3.25	3.65	4.23
24	1.95	2.03	2.12	2.25	2.37	2.51	2.70	2.97	3.30	3.71	4.29
25	1.98	2.06	2.16	2.28	2.41	2.55	2.74	3.02	3.35	3.77	4.36
26	2.01	2.09	2.19	2.32	2.45	2.59	2.79	3.07	3.41	3.83	4.44
27	2.05	2.13	2.23	2.36	2.49	2.64	2.84	3.13	3.47	3.90	4.51
28	2.08	2.17	2.27	2.40	2.53	2.68	2.89	3.18	3.53	3.96	4.59
29	2.11	2.20	2.31	2.44	2.57	2.73	2.94	3.23	3.59	4.03	4.67
30	2.15	2.24	2.35	2.48	2.62	2.78	2.99	3.29	3.65	4.10	4.75
31	2.19	2.28	2.39	2.52	2.66	2.83	3.04	3.35	3.72	4.18	4.84
32	2.23	2.32	2.43	2.57	2.71	2.88	3.10	3.41	3.78	4.25	4.93
33	2.27	2.36	2.47	2.61	2.76	2.93	3.15	3.47	3.85	4.33	5.03
34	2.31	2.40	2.51	2.66	2.80	2.98	3.20	3.53	3.92	4.41	5.12
35	2.35	2.44	2.56	2.70	2.85	3.03	3.26	3.59	3.99	4.49	5.21
36	2.40	2.49	2.61	2.75	2.91	3.09	3.33	3.66	4.07	4.58	5.32
37	2.45	2.54	2.66	2.81	2.97	3.15	3.39	3.74	4.15	4.68	5.42
38	2.50	2.59	2.71	2.87	3.03	3.21	3.46	3.82	4.24	4.77	5.53
39	2.54	2.64	2.77	2.92	3.09	3.28	3.53	3.89	4.32	4.86	5.64
40	2.59	2.69	2.82	2.98	3.15	3.34	3.60	3.97	4.41	4.96	5.75
41	2.64	2.74	2.88	3.04	3.21	3.41	3.67	4.05	4.50	5.06	5.87
42	2.69	2.79	2.93	3.10	3.28	3.48	3.75	4.13	4.59	5.16	5.99
43	2.74	2.84	2.99	3.16	3.34	3.54	3.82	4.21	4.68	5.27	6.12
44	2.80	2.90	3.05	3.22	3.40	3.62	3.90	4.29	4.77	5.37	6.24
45	2.85	2.96	3.11	3.28	3.47	3.69	3.97	4.38	4.87	5.48	6.36
46	2.91	3.02	3.18	3.35	3.54	3.77	4.06	4.47	4.97	5.59	6.50
47	2.97	3.08	3.24	3.42	3.62	3.84	4.14	4.56	5.07	5.71	6.63
48	3.03	3.14	3.31	3.49	3.69	3.92	4.22	4.65	5.17	5.82	6.77
49	3.09	3.21	3.38	3.56	3.77	4.00	4.31	4.74	5.27	5.94	6.91
50	3.15	3.28	3.44	3.63	3.84	4.08	4.39	4.84	5.38	6.06	7.04
51	3.22	3.34	3.51	3.70	3.92	4.16	4.48	4.94	5.49	6.18	7.19
52	3.28	3.41	3.58	3.78	4.00	4.25	4.57	5.04	5.61	6.31	7.34
53	3.35	3.48	3.66	3.86	4.08	4.33	4.66	5.14	5.72	6.44	7.48
54	3.41	3.55	3.73	3.93	4.16	4.41	4.75	5.24	5.83	6.57	7.63
55	3.48	3.62	3.80	4.01	4.24	4.50	4.85	5.35	5.95	6.70	7.78

The Railways,

by F. Q. DEN HOLLANDER,

Engineer, President of the Netherlands Railways.

(Extract from the special publication : « Koninklijk Instituut van Ingenieurs — Jubileum 1847-1947 », published on the occasion of the Centenary of the Royal Institute of Dutch Engineers. — Supplement to No. 37 of the De Ingenieur of the 12th September 1947.)

For the hundred years and more during which the railways have been in existence in the Low Countries, there has always been a very close relation between their operation and technical progress. Compared with the first three quarters of the century during which they have been in existence, when railway operation and technique developed calmly and slowly, evolution has been much faster since the first world war. On one side, the development of new methods of communication involved finding new ways; on the other, technical possibilities were greater, thanks to the development of scientific research, the arrival on the market of more adequate materials, and the utilisation of electric energy as a source of motive power for traction. The period between the two world wars can be considered as a period of transition, during which, for example, the explosion engine and internal combustion engine were finding their place, without however becoming of great importance. The destruction of much railway equipment and the damage suffered during the second world war have however resulted in conditions favourable for applying boldly the new techniques in order to realise an up-to-date and efficient operation.

As regards this technical development, attention should be specially directed to the role of the railways and the place they have gained in the national and international organisation of transport. Their economic field of action would seem to lie chiefly in the transport of

bulk goods over short distances, and linking up the primary and the secondary towns of the country over longer distances. Their mission has always been to assure a system of transport characterized by its security, regularity of working under all climatic, service and national conditions, and the greatest possible economy in carrying out national and international transport.

When the future of railway operation is considered at the present time, it is difficult to indicate in a concrete fashion similar developments for all sections of the technique. The only common factor that can be pointed out in every case is the end to which the efforts of the railway engineer are directed within the framework of the functions of a railway as indicated above, i.e. to achieve the greatest possible security and as efficient an operation as possible.

The aspect which characterizes the railway system in Holland depends to a large extent upon the state of the soil. Precisely in those places where the railway system is dense, the foundation of the permanent way often rests upon very weak layers of peat or clay. Therefore with the assistance of soil mechanics, it will be necessary to undertake work in the future to overcome two phenomena which are obstacles to maintaining the permanent way in good condition, namely subsidence, and irregularities of the surface in order to make sure that the railways of the future will have the same standard of safety at the speeds desired.

Special attention must be given to the

maintenance of the track, which involves heavy expenditure at regular intervals, especially on lines with fast and frequent traffic.

For reasons of economy, and also to improve them at the same time, the track on main lines with frequent services will gradually be equipped with 63 kgr./m. (127 lbs./yard) rails, while wood sleepers will continue to be used.

In laying the rails which will be set at 1 in 30, the choice lies between rolled steel bearing plates and rolled steel sole plates, the latter replacing the cast plates now in use. In making this choice, based on the results of trials to be carried out, account must be taken of the advantages which may be expected from being able to use rolled steel plates of the same section for all kinds of rails and of being able to make all the bearing plates used on the railway to a standard pattern.

Where necessary gravel ballast will be replaced by broken stone, which make a more stable bed, and gives improved drainage, and consequently increases the life of the track.

Again with the object of reducing maintenance costs, this new type of track will be laid with rails 45 m. (147' 7½") long, or even longer. These long rails will be obtained by electrically welding together 15 m. (49' 2½") rails continuously and cutting them into 45 m. lengths by a saw cut in the middle of a 15 m. length. When the rails obtained in this way are joined up again by means of fish-plates, the ideal joint is obtained. Wear of both the track and the rolling stock will be considerably reduced by having fewer joints and by the improved quality of such joints.

In the case of large lattice girder bridges, these are at present being carefully studied in order to discover the most economic design from the point of view of materials and maintenance. Welded tubular air tight bars of A 37 steel will be used, or assemblies using

rivetted joints, both methods being compared with entirely rivetted construction in L 52 steel. In the same way, in order to economise in the maintenance of small fixed bridges, when old bridges have to be replaced or rebuilt, concrete bridges will be made with a continuous layer of ballast. In the case of moveable bridges, which have to be balanced by counterweights, the possibility of using parts made of rolled aluminium is under investigation.

The reconstruction of the stations that have been destroyed and their equipment will be made as rationally as possible, taking into account the fact that electric, diesel-electric or diesel traction may replace steam traction.

As the station is the point of contact between road and rail traffic, special attention must be given to transshipment facilities in either direction when building the new stations. Station approaches must be designed on as generous a scale as possible so as to give easy access to the buses and taxi ranks, and in order to facilitate the arrival and departure of passengers using private cars, and the trams. In addition when designing the entrances to stations, the ways in and out must be so planned as not to impede circulation or lead to other difficulties. The necessary waiting room facilities must also be provided for passengers waiting for connections.

As has already been done in the case of the Amsterdam C.S. and The Hague H.S. stations, the waiting rooms and cloakrooms will be situated on a level with the station platforms. In other towns, the drawback of level crossings will be overcome by raising the track and making subways. In order to adapt itself to the requirements of town passengers, in the future the railways should run as far as possible into the centre of cities, and where possible transport facilities should be given to the housing estates around the towns.

Several marshalling yards will have to

be equipped on different lines, chiefly from the point of view of the number of sidings provided, in combination with carrying out the present system of composing trains by means of loaded wagons. At each of the principal stations of the group, in order to get as few as possible breaks in the routing of wagons owing to shunting en route, complete trains will be formed to run straight through to other principal stations in the group. The shunting sidings of the principal stations of the group are not designed for working in this way and will have to be adapted. A certain number of auxiliary shunting sidings can be suppressed.

As regards signalling, in order to increase the safety, reduce operating costs, and obtain high output as regards the capacity of stations and sections of line, the most up-to-date safety measure will be applied.

One of these methods is *centralised traffic control (C.T.C.)* which consists of operating the track equipment and signals in a complete section — preferably single track — 100 km. (62 miles) long or more, for example, from a single central point with automatic control of the position of trains shown on a table. On the line, this method provides at the same time for the application of the automatic block system.

In the case of large stations, the so-called N-X system (for *entrance*, start of the route, and *exit*, end of the route) is under consideration. In this method the train movements are controlled by means of buttons sited on a table diagram of the station (table on which the equipment and signals are shown). For any given train movement, it is only necessary to press a button N (*entrance*) and another button X (*exit*) which will throw all the equipment into the desired position and work all the necessary signals for the train movement in question regardless of the length of time it takes (for example a « passage »). If more

than one route is possible, that to be taken is given automatically according to a prearranged order. The system includes — like the C.T.C. method — complete control of all the track occupied and the covering signals.

For ordinary double track sections of line, the automatic block system in use since 1926 will have to be completely adapted with day and night light signals instead of semaphore arms. When such signals are used to the fullest extent, in their three possible positions, each signal can be used as a stop signal (red or green), and at the same time as a warning signal (yellow or green), the whole therefore making use of red, yellow or green lights, which makes it possible to run trains in more rapid succession and consequently obtain better use of the line. The protection of unprotected level crossings by means of flashing lights will also be greatly extended.

For using light signals at junctions and in stations, a new system of signals has been designed, completely different from the old semaphores.

With these, red is now shown when the signal can be run past, while the information as to how this can be done is given in terms of the speed only, and not of direction. To do this, three speeds have been selected (a maximum, a minimum, and an average speed) which are shown by the level of the signal light.

The foundation of the safety signal « road occupied » and of the automatic block system is the *track circuit*, i.e. a circuit of current through the rails which is short-circuited by a train and puts the signal to danger. The latest novelty in this method is the system known as « *coded track circuit* » in which rhythmic currents are sent through the rails according to a definite code. This system considerably increases the safety. In addition if automatic train control is afterwards adopted, this can be organised ideally by continuous automatic control of the speed of

the train according to the conditions prevailing in the section of line in question as ascertained from the coded track circuits. At the same time the signals can be repeated in the *driver's cab*, which makes it possible to imagine that ultimately it will be possible to do away with signals along the line.

As far as traction is concerned, great modifications will have to be taken into account. Steam will be completely given up; the position as regards available energy will make this necessary. The ratio between supply and demand as well as the evolution of fuel prices on the different markets have changed in such a way that the question of the motive power has become one of the most pressing problems.

Owing to certain considerations of policy as regards available energy and in view of the great technical and economic advantages involved in the application of electric traction, diesel-electric traction, and diesel traction, the railways are electrifying a large part of the system, so that in the near future there will be nearly 1 500 km. (932 miles) of electrified lines. On the main lines the passenger traffic will be worked mainly by sets of rail motor coaches; at the same time, for long distance journeys there will be trains hauled by electric locomotives. On the non-electrified lines, either diesel-electric locomotives or diesel-electric railcars will be used. The shunting services will be covered by diesel-electric tractors. For goods trains on the main lines, electric locomotives will be used; on other lines diesel-electric tractors. The number of different types will be kept as low as possible.

As far as diesel-electric traction is concerned, this programme may be amended owing to the development of the hot air engine, especially as transmission is simplified thereby. The turbine gas locomotive has certain features which makes it seem less suitable for our country.

The power of locomotives and railcars will be increased. In Holland, the maximum speed for passenger trains will probably be increased to 150 km. (93 miles)/h., and that of goods trains to about 100 km. (62 miles)/h. On long runs special attention must be given to the maximum speed, and for shorter distances to the starting speed.

The application of the up-to-date methods of traction mentioned above, with a limited number of types, will be an important contribution to increased efficiency of operation; the turn-round of rolling stock will be greatly increased, the maintenance costs will be reduced, and the repair shops can be reduced in number.

As regards passenger stock, further progress is likely from certain points of view. No doubt everything will be done to increase the comfort still further. The possibility of making it as easy as possible to board and leave the trains is being investigated.

The interior lighting is being specially considered, probably by the use of tubular lighting fittings, so that passengers will have a good light to read by.

As regards ventilation, the method of heating and ventilating by pulsated air, already used on streamlined stock, will be installed.

The use of air conditioning, which also makes it possible to cool the air during hot weather, does not seem to be very suitable for the Low Countries. The statistics of the Royal Meteorological Institute which cover 25 years, show that on the average there are not more than 10 days in each year when the temperature is sufficiently high to make cooling of the air desirable. The installation of air conditioning is expensive and the equipment weighs a lot.

There is room for improvements in the running of the bogies of coaches and locomotives.

Special attention will be given to reducing the braking distance, or at least

to keeping within the present limits even though the speed is increased.

The air resistance of the trains will be reduced by streamlining them as far as possible.

As regards goods waggons, the four wheeled waggon will continue to be the type most widely used. Roller bearing axle boxes will be used exclusively. The goods waggons will be so designed that loading and unloading will be an easy matter.

In addition every effort will be made to reduce the weight whilst increasing at the same time their capacity, in particular by the use of light alloys.

In the case of internal traffic the use of automatic couplings will gradually be made general; their use in international services cannot as yet be definitely pronounced upon however.

Refrigerator transport is likely to be considerably extended in the future. The freezing of food stuffs has been developed on a large scale, which has opened up new markets in several countries. At the same time the low temperature freezing industry has been greatly extended. Dry ice has so far been used in the refrigerator vans for the transport of such products, but this is a costly method and gives rise to drawbacks from the practical point of view. The use of container waggons with mechanical means of refrigeration is too costly. Endeavours must therefore be made to equip refrigerator vans with some suitable type of refrigerator, and it is probable that the use of eutectic ice will be considered.

By its very nature the change over to other methods of traction will have profound repercussions on the construction, equipment and organisation of the shops. The transition period will however be a long one, in view of the fact that for many years to come the new methods of traction will be used side by side with the old; this transition period will there-

fore have certain special features. Gradually the steam locomotive shops will have to be altered in such a way as to be able to carry out the precision work involved in connection with motors and the equipment used with diesel-electric and electric traction.

The kind of work will be radically changed; new tools, modified working methods, new measuring methods and also new buildings will come into use. The maintenance of units in the past did not require very long buildings but facilities for moving the locomotives transversally. In the future the shops will have to be equipped with long sections of track so that the complete sets can be taken straight in, since it is difficult to divide them up.

Although technically, and from the point of view of design, the new stock will be finer than ever, it is expected that the equipment and space required to keep it in perfect repair will be less rather than more in comparison with the period before modernisation.

If the most recent technique is applied, the traffic requirements can be met economically. For this purpose the safety, speed and frequency of the services must be brought to the highest possible level. For the most part safety will be obtained by the introduction of the new safety methods. The speed will be obtained above all by the modern methods of propulsion mentioned above and by the improvement of the permanent way and its bed. The frequency of the services will depend upon the new organisation of the passenger trains, the special object of which will be to link up the outer regions with the centre. At the same time, the increase in the number of trains will impose a limitation on their length; in this way the services can be more easily adapted to actual conditions, and the arrangement of the stations simplified. The time spent in the stations can be reduced by the use of automatic and central coupl-

ing, which makes it possible to joint up or divide rakes in a very short time.

The application of these different techniques will enable the railways, as stated above, to carry out their task to the utmost. The volume of traffic is increasing ever more and more; the ratio between the density of the population, economic activities, and the volume of traffic is becoming more and more inter-related. The following figures stress this very convincingly. In 1878, there were 4 000 000 people in Holland, and the railways ran 0.5 thousand million passenger-kilometres, i.e. 125 km. (77 miles) per person. In 1938, the population had increased to 8.7 millions and the number of passenger-kilometres to 3.1 thousand million, so that at that period each person travelled \pm 360 km. (223 miles) a year by rail. In 1946 the total number of passenger-kilometres reached 5.6 thousand million, and the average per person 600 km. (372 miles).

In the future the people are likely to travel still more owing to the strengthening of the economic life of the country and the spread of industrialism, especially in the provinces other than Northern and Southern Holland. On this basis if the population of Holland has increased to 11 000 000 by 1960, each of whom travels 740 km. (460 miles) a year, the railways will have to run some 8 thousand million train-kilometres in that year, which in comparison with pre-war passenger traffic is an increase of 260 %.

As for goods traffic, it is harder to estimate what its probable evolution will be. The railways, in spite of the coming of new methods of transport, will continue to occupy an important place for the bulk transport of goods. Here again technical progress will show new possibilities to obtain the greatest possible improvement. The use on a large scale of containers of all sorts must be considered together with a special type of

lorry for transporting containers to and from the railway station.

As in the past, the authorities will not be able to remain aloof in the end from the evolution of different techniques in the sphere of communications, seeing that their evolution has important repercussions from the point of view of the national organisation of transport, which repercussions are continuous and economic and consequently tend towards co-ordination between the different branches of transport, so that in the future they will only be able to obtain an ordered application of the new methods if, from the point of view of transport, they intervene in order to regulate them and achieve a harmonious allocation of the traffic between the different branches of the transport industry. Within the framework of such co-ordination, the railways will collaborate very closely with transport by water, road and air, conscious of their special role of a national undertaking to whom a specific task has been allotted.

The above is a *brief sketch* of the future. To what extent it will be realised depends in the first place on the economic situation of the country and its railways. The Netherlands Railways will make every endeavour, within the limits of economic possibilities, to profit in full by technical progress. Already in 1863, the State Railway Company took upon itself the obligation to take all the necessary steps to insure that its operation, from the point of view of speed and safety of transport, the design of the stock, the equipment of the stations, and all other branches of the service, was at least the equal of that offered by the best railways in other countries, and that as far as possible, from the point of view of all the improvements introduced elsewhere, an equal level was maintained by them.

This line of conduct will be that which the Netherlands Railways will also endeavour to follow in the future.

Individual axle drive.

Mechanical systems used on electric locomotives and railcars, with an indication of the results obtained in service on railways of all kinds,

(Continued*)

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Chapter IV. (Continued)

DRIVING MECHANISM USING SPRINGS (OR RUBBER) WITH TRANSMISSION BY GEARS.

Figure 108 shews a front view of locomotive No. E.4813 of the former P.O.-MIDI (series 4807-4822, built in France); it is, therefore, exactly the same type of locomotive as that shewn in Figure 107.

Figures 109 to 112 shew various details of locomotives of the complete series (4807-4824) ⁽⁶⁸⁾, viz.: part views in elevation and section (figs. 109-110), the drive mechanism, driving wheel centre and hollow shaft (fig. 111) and finally two complete driving axles (one wheel set) with hollow shaft and gear wheels (fig. 112). These locomotives have bilateral drives and gears and, contrary to the locomotives in figures 104 to 106, an even number of spring couples is used (6 arms instead of five). In addition, the couple supports are not monobloc,

but divided vertically, as on the PRR (figs. 75 and 77).

It is interesting to compare figure 104 with figures 107 and 108, and figure 106 with figure 112. The first figures are those of the former P.O., the second those of the former MIDI, the two systems subsequently amalgamating (P.O.-MIDI) before the general embodiment in the SNCF in 1938. Also compare figure 111 with 75 and 77 of this Chapter, dealing with PRR locomotives. We shall not describe the details which can be readily seen in the various figures (securing of the couple supports, gear rim, gear wheel centre with hollow shaft, etc.).

On the main lines, it can be said that the quill cup drive mechanism, with spring couples of the Westinghouse or

(*) See *Bulletin of the International Railway Congress Association*, Nos. of September, October and December 1947, pp. 823, 885 and 999 respectively, and No. of February 1948, page 73.

⁽⁶⁸⁾ See *Revue Générale d'Electricité*, Paris, 11th August 1934 (Mr. LEBOUCHER) and *Revue Générale des Chemins de Fer*, Paris, November 1933.

AEG-Kleinow type, has given satisfactory results. This mechanism is, however, considered to be fairly complicated in assembly and it is thought that the tendency will be towards the use of rubber

these driving mechanisms which were fitted, during their time, on express locomotives of the Midi Railways in France (series E.3100, 10 locomotives, 2-C₀-2, 1923-1928, vertical motors, and series



Fig. 108. — Express locomotive No. 4813, 2-D₀-2, of the former MIDI, France (same series as fig. 107). Quill cup drive with an even number of couples.

(see under Pennsylvania RR, second part of *b*) of this Chapter) or to other mechanisms which may be developed later.

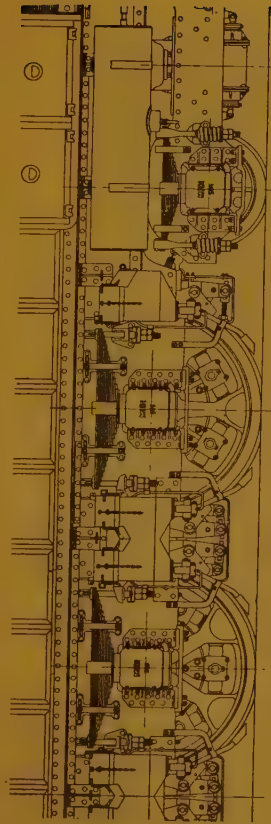
Under 5) (**). — So far as is known, there has been no further application of

E.4801-6, six locomotives, 2-D₀-2, 1932, horizontal motors) (followed by locomotives 4807-4824 described above).

Under 6). — New uses of the *Bianchi* arrangement with laminated springs.

(**) See *Bulletin of the International Railway Congress Association* for December 1947, p. 1001.

Fig. 109. — Elevation of the 2nd., 3rd. and 4th. (right to left) axles of one of the 2-D₆2 locomotives of the series 4807-4824, SNCF (see figs. 107 and 108).



Plans Als-Thom.

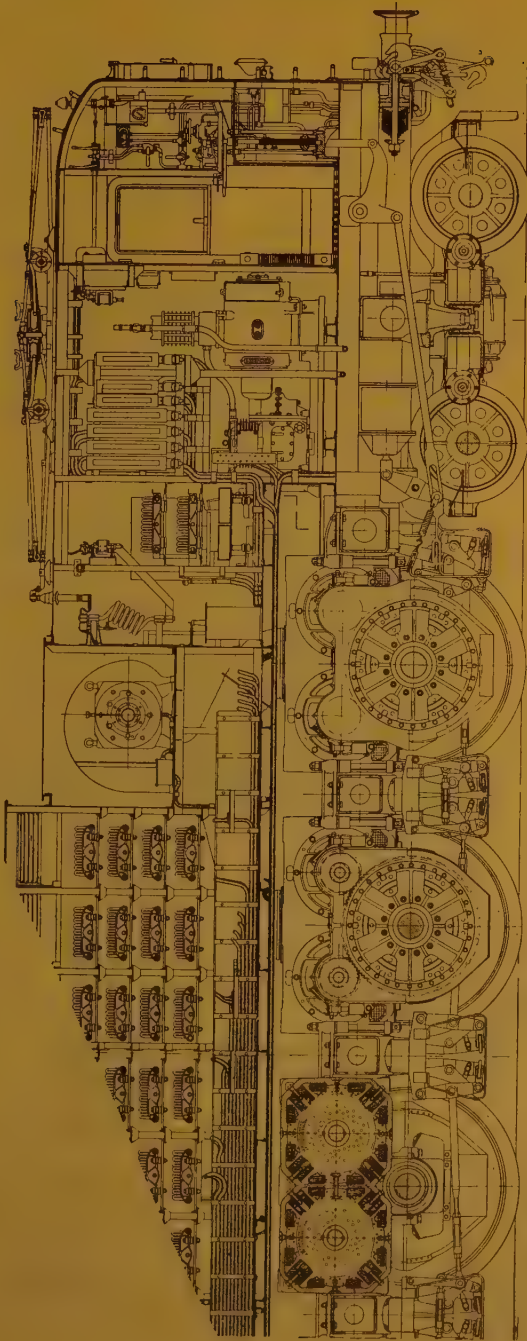


Fig. 110. — Part longitudinal section of locomotives in figs. 107 to 109, showing details of the motors, gears and drive.

Uses of the Bianchi mechanism ⁽⁶⁹⁾ prior to 1932 were described on pages 67-69 (figures 140-142) of Cde. indiv. This dealt with the fitting of 12 locomotives, type 2-C₀-2, series E.326, Nos. 001 to 012, and eight locomotives, type 2-B₀+B₀-2, series E.428, Nos. 001-008.

of 4 000 H.P. hourly rating, maximum operating speed also 130 km./h., tare 132 tons; a brief description of these will be given in the second part of this Chapter.

All these machines are for 3 000 volts DC. ⁽⁷⁰⁾.

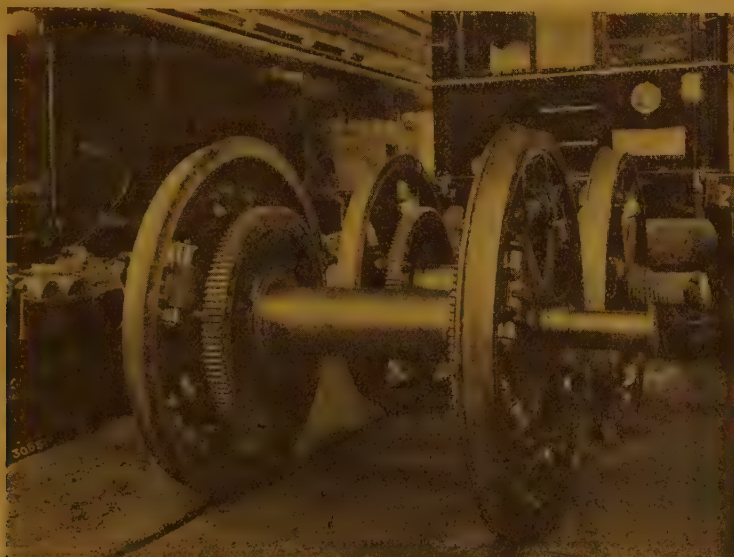


Fig. 112. — Two driving axles complete, for the locomotives shewn in figs. 107 to 111. Bilateral gears and drive.

Of the 2-C₀-2 locomotives, of 2 600 H.P. hourly rating, maximum operating speed 130 km./h. (80 m.p.h.), tare 112 tons (fig. 142 of Cde. indiv.), 12 are at present in service, as well as 300 2-B₀+B₀-2

Bibliographical references will also be given, in the form of notes to the text, in the second part of the Chapter, together with references to developments of the mechanism.

⁽⁶⁹⁾ The engineer Giuseppe BIANCHI, inventor of the arrangement, was for long in the Mechanical Engineering Department of the Italian State Railways, finally as Chief of Electric Rolling Stock. Florence, and was then attached to the « Compagnia Generale d'Elettricità », Milan. Appointed by the Allied Occupation Authorities, shortly after the Armistice in 1945, Controller of Italian Railways, he became in 1947 Director in charge of the North of Milan Railways « Ferrovie Nord-Milano » FNM.

⁽⁷⁰⁾ Output at the sub-stations = 3 700 V.; average contact line tension = 3 400 V.

As in most of the arrangements, the Bianchi system has undergone improvements as a result of experience in service. The variations will be described, both for locomotives and for railcars and fast railcar sets, in the second part *b)* of this Chapter, with new arrangements. In its original state, the Bianchi arrangement had the disadvantage of a lubrication system which was difficult to maintain

shews an axle assembly for the fast railcar sets (electric) (triple set articulated on four bogies) known as the «*elettrotreni*», of which details and bibliographical references will be given in the second part of this Chapter, together with developments of the arrangement. The first of these sets have been in service on the Milan-Bologna-Florence-Rome-Naples (*Direttissima*) since 1935/36. They

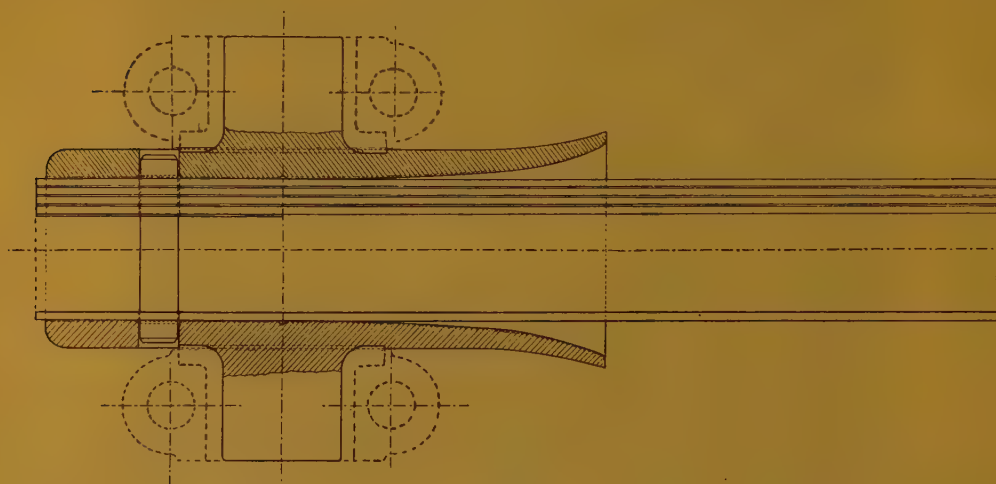


Fig. 113. — Arrangement of the drive springs for the Bianchi mechanism for Italian locomotives. See figs. 140 to 142 of *Cde. indiv.*

in service (four lubricators for each set of laminated springs, 48 per axle or 144 to 192 Stauffer lubricators per locomotive, see fig. 140 of *Cde. indiv.*). This defect really removed itself, since it became obvious that the lubricators were unnecessary, and they were left off.

Complementary to figures 140 and 141 of *Cde. indiv.*, figure 113 shews a set of springs of the original Bianchi mechanism.

The original Bianchi mechanism has also been used on railcars. Figure 114

run at a speed of 160 km./h. (99 m.p.h.) and in trials have reached a speed of 205 km./h. (127 m.p.h.). 3 000 volts DC. current is used as already stated.

b) PART TWO.

(of Chapter IV).

We pass now to *new* spring mechanisms, developed for the most part from those in the first part of this Chapter. They will be dealt with in the order of the importance which we consider they

merit, according to their present state of development, remaining grouped, however, in the various categories.

«Quill cup drive» with rubber.

We commence with quill cup drive with rubber blocks in place of spring couples, and for comparison refer to

Figures 115, 116 and 72 (r.h. side) shew the first arrangements ⁽¹⁾ which were tested on several GG1 locomotives, and figure 117 (reproduction of PRR drawing) the actual arrangement of 1942 which has since been adopted (from 1942 to end of 1946) on most of the locomotives of the classes :

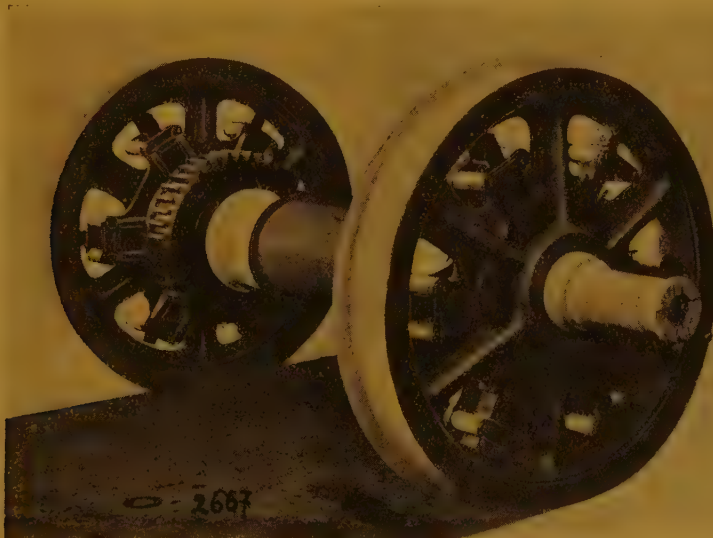


Fig. 114. — Axle with bilateral drive and unilateral gear on hollow shaft, for the express railcar sets «elettotreni» (1935/36) of the Italian State Railways, Breda construction. Max. working speed, 160 km./h. (99 m.p.h.). See second part of this chapter with illustrations of the set and bogies.

figures 72, 73, 74 and 76 of the first part of this Chapter, and to the notes to items 2 and 4 of Table A (see fig. 70).

In 1938/39, the Pennsylvania RR carried out the first trials using rubber blocks instead of spring couples, the remainder of the quill cup drive remaining almost identical.

GG1, comprising 139 locomotives (Nos. 4800 to 4938) and

P5A, comprising 92 locomotives (Nos. 4700 to 4791).

This mechanism, which the PRR calls the rubber cup drive, was standardised for GG1 locomotives. With regard to the P5A, 2-C₀-2 type (see fig. 164 of Cde.

⁽¹⁾ The photographs were taken by the author, at the Sunnyside depot, New York, and at the Altoona Works (Pa.) of the Pennsylvania RR, in June, 1939.

indiv., p. 79), these were successively modified with a fitting very similar to that in figure 117, of the GG1 locomotives and, the Author believes, with uni-

thought that it may undergo great development in the future. It may be remarked in passing that the mechanism described on pages 77 to 79 of Cde. indiv. (fig. 163) of the General Electric Company has been removed from the P5A class locomotive, series 4700 (former No. 7899? P5 class) and is no longer in use, the cup drive being preferred in operation. The same remark applies to the two 2-B₀-2, 01 class, locomotives mentioned in the left-hand column of page 78 of

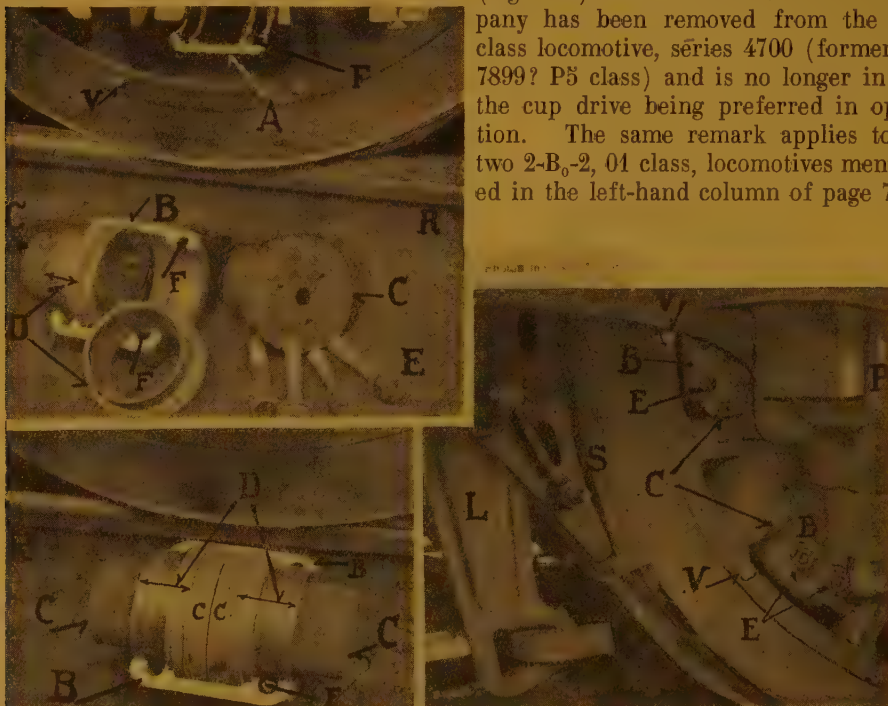


Fig. 115. — First use of rubber cup drive in quill cup arrangement, Pennsylvania Railroad PRR.

- A & B : two-part support, divided vertically. A = lower part fixed to the hollow shaft arm, and B = the outer part fitted to A by bolts E through the holes F.
 C : rubber pad set in the supports A and B with metal retaining rings.
 L : equaliser arm of the brake blocks S — adjustable.
 V : wheel-tyre fixing bolts.

(See fig. 72, left, and 116.)

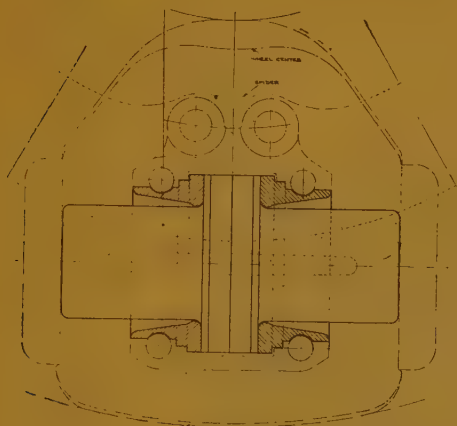
lateral gears and mechanism only, reversed on successive axles (see figs. 70 and 74, in contrast to figs. 76 and 77).

The Pennsylvania RR is very satisfied with its rubber cup drive and it is

Cde. indiv., and to the fitting described on pages 76-77 (fig. 161) of Cde. indiv. (see fig. 35 of this Chapter) of the Westinghouse Co.

Apart from the « cup » — including

rubber cup — drives, only a single example of the experimental mechanism has been retained, that described in Chapter III (figs. 16 to 18 and Cde. indiv., fig. 63), the Buchli arrangement (Brown-Boveri).



From PRR drawing.

Fig. 116. — Section of the rubber blocks fitted in fig. 115, Pennsylvania Railroad (original arrangement on GG1 locomotives).

Flexible arrangements with push-rods.

The Meyfarth-Sécheron arrangement⁽⁷²⁾ is based on the same principles as the quill cup drive, from which it may be considered to be derived, but the compression of the springs, instead of taking place directly from thrust plates on the wheel spokes, is effected through push-rods with rounded ends. The axes of the rods incline slightly, according to the relative movements of the axle in relation to the hollow shaft to which the spring supports are attached.

As we shall see, this arrangement has two fairly divergent applications, parti-

cularly as regards the sizes of the components, these being the different types for *locomotives* and for *railcars*.

The locomotive type is used for driving wheel diameters of between approximately 1 100 and 1 600 mm. ($3'7\frac{5}{16}''$ and $5'5''$) and for an axle load of about 15 tons, whilst the railcar type was designed for a wheel diameter of about 900 mm. ($2'11\frac{1}{2}''$) and an axle load of 11 to about 14 tons.

This mechanism will be dealt with before the other developments of the quill cup drive (particularly those of Oerlikon and Brown-Boveri, with springs, which will be described later in this Chapter) because the latter are rather more for railcars, or at least for light locomotives, and for ratings in the region of 300 to 600 H.P. per axle at the most.

The *locomotive type* and its uses will be described first.

Fig. 118 shews the first application which was made in June, 1935, on one of the driving axles of locomotive 10204, type 1-C₀-1 ($Ae^3\frac{3}{5}I$) of the Swiss Federal Railways SBB-CFF (see figs. 77 and 78 of Cde. indiv.).

Up to the end of 1939 this axle had completed more than 300 000 km. (186 400 miles) and had not given any trouble in service.

In the beginning wear on the sockets was fairly heavy, but since the caps were modified and more suitable metals used, the maintenance of this mechanism has given no trouble.

Fig. 119 shews a section of a spring element complete, and figs. 120, 121 and 122 the separate components, partial as-

⁽⁷²⁾ The engineer G. MEYFARTH, who patented this arrangement, was Director-General of the Sécheron Works (SAAS) of Geneva.

sembly and successive assemblies which are somewhat divergent.

The axle driving mechanism operates as follows: the driving effort of the gear wheel compresses the spring (in one direction or the other, according to the direction of travel) by the action of the external cylinder/sleeve (element support). As soon as the spring begins to compress,

the amount of play of about 3 cm. mentioned above, and as the parts are very strong the reciprocal friction is insignificant provided the lubrication is effective and the surfaces are kept clear of sand. As already stated, when there is play between the hollow shaft and the axle, the push-rods take up a slight inclination, but no friction arises from



Fig. 118. — Driving axle fitted with flexible drive of spring couples with push rods, Meyfarth-Secheron system; on trial (1935) on the 1-C₅-1 locomotive, No. 10204, of the CFF, Switzerland. Unilateral gear wheel on hollow shaft. Diameter of tread of tyre, 1 610 mm. (5'3³/₈").

play arises — up to 3 cm. ($1\frac{3}{16}$ ") — allowing the internal cylinder/sleeve to slide in relation to the external supporting cylinder. The spring, under compression, sets up a flexible drive on the internal cylinder/sleeve which transmits the drive by the corresponding push-rod to the body of the wheel.

The maximum relative movement of the two cylinder/sleeves corresponds to

this, but only a very slight roll, thanks to the spherical heads of the push-rods. To an even better degree than with the quill cup drive, the springs are subject to compression without any deflection.

Fig. 122 shews details of the assembly in elevation and cross-section.

The principal advantage of this mechanism, in our opinion, due to the arrangement of the component parts, lies in

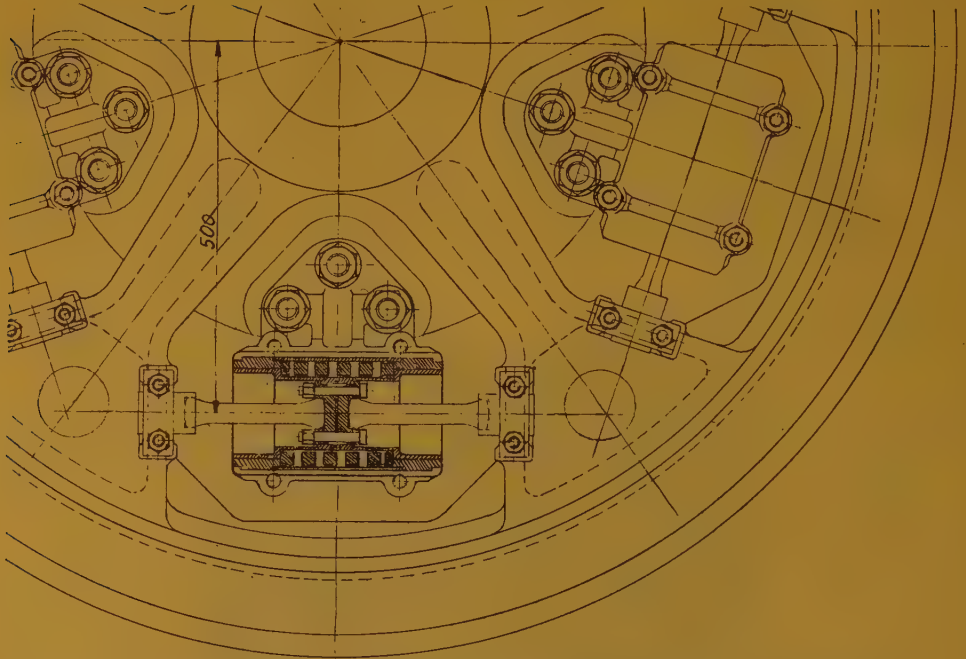


Fig. 119. — Vertical section of spring couples with push rods, original patented system.
This practically represents a working diagram.



Fig. 120. — Component parts of the Meyfarth-Secheron arrangement of fig. 122. Note the dished plates for the rounded ends of the push-rods, the interior ones are driven to one side or other by compression of the spring under the driving effort of the gear wheel.

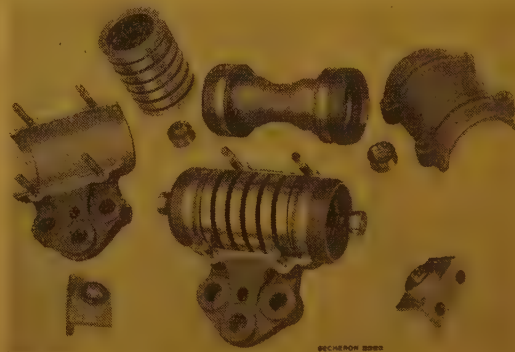


Fig. 121. — Same parts as fig. 120, but of more recent design. The assembly of the component parts can be seen; the central unit is here in one piece (screwed head).

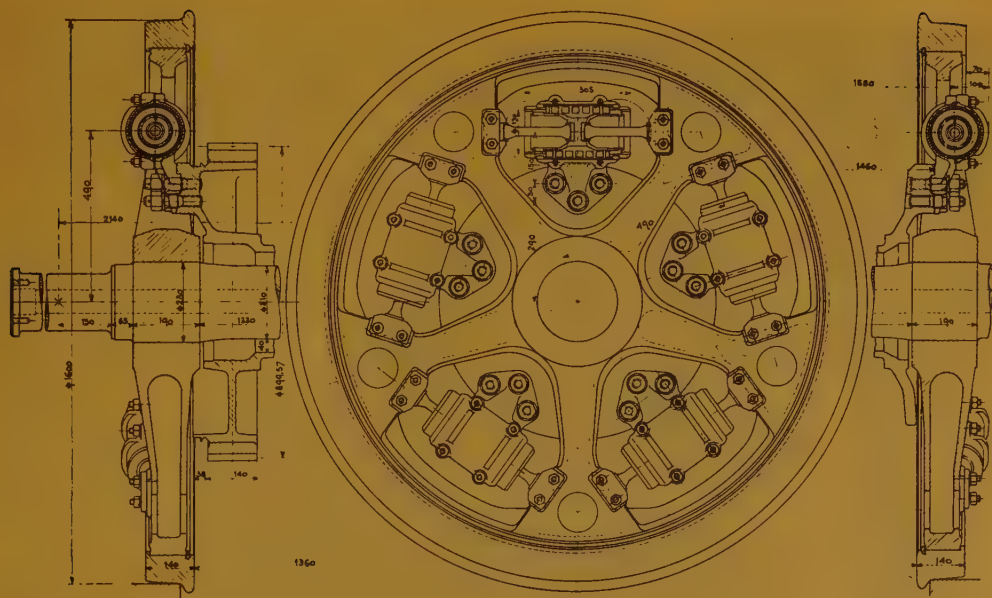


Fig. 122. — Elevation and cross-section of a SNCF driving axle with 1 600 mm. wheel, with Meyfarth-Secheron push-rod mechanism. See figs. 118, 120, and 121.



Fig. 123. — M. type locomotive, C₃+C₃, No. 604, series 604-620, Swedish State Railways, SJ, fitted with push-rod drive, Meyfarth-Secheron system. Same locomotive as fig. 93 [see *b*) above, fig. 91].



Fig. 124. — Double Diesel-electric locomotive of the SNCF, No. 262-AD-1 (S.E. region — PLM), 4 200 H.P., 130 km./h. (80 m.p.h.) for express service on the Paris-Lyons-Marseille-Menton line (see fig. 88).

the fact that it can be of a very small size, which permits of its use on wheels of only 900 mm. ($2'11\frac{1}{2}''$) diameter (rail-cars). Its behaviour as regards the dynamic stresses set up by rotation and relative movement is similar to the quill cup drive.

We now pass to the *uses* on *locomotives*, apart from the one already mentioned (CFF, fig. 118).

The most extended use is that on 19 locomotives of the Swedish State Railways «Statens Järnvägar» — SJ — of which two were 1-D₀-1 express locomotives, type F, Nos. 602 and 603, in 1942 (similar to those in figs. 91 and 92, see remarks under *a*) following fig. 90) and the 17 C₀+C₀ freight locomotives, type M, Nos. 604-620, in 1944, a dimensioned sketch of which is shewn at fig. 93. Fig. 123 shews the first of these locomotives.

The Swedish Railways consider this arrangement satisfactory, provided that the eccentricity of the hollow shaft is reduced to as small an amount as possible and sanding-up of the axles is avoided. Otherwise, the excessive oscillation will cause the push-rods and other parts to break. The quill cup drive is less sensitive in this respect (see remarks on fig. 92) but it is clear that sanding-up of one or more axles and the casting of sand on to the sliding surfaces must be avoided, in view of the excessive dynamic stresses which result ⁽⁷³⁾.

The following applications of the mechanism to locomotives are set out in chronological order :

— the Diesel-electric super-locomotive No. 262-AD-1, 2-C₀-2+2-C₀-2, built for

(⁷³) Compare with left hand column of page 66 of *Cde. indiv.*

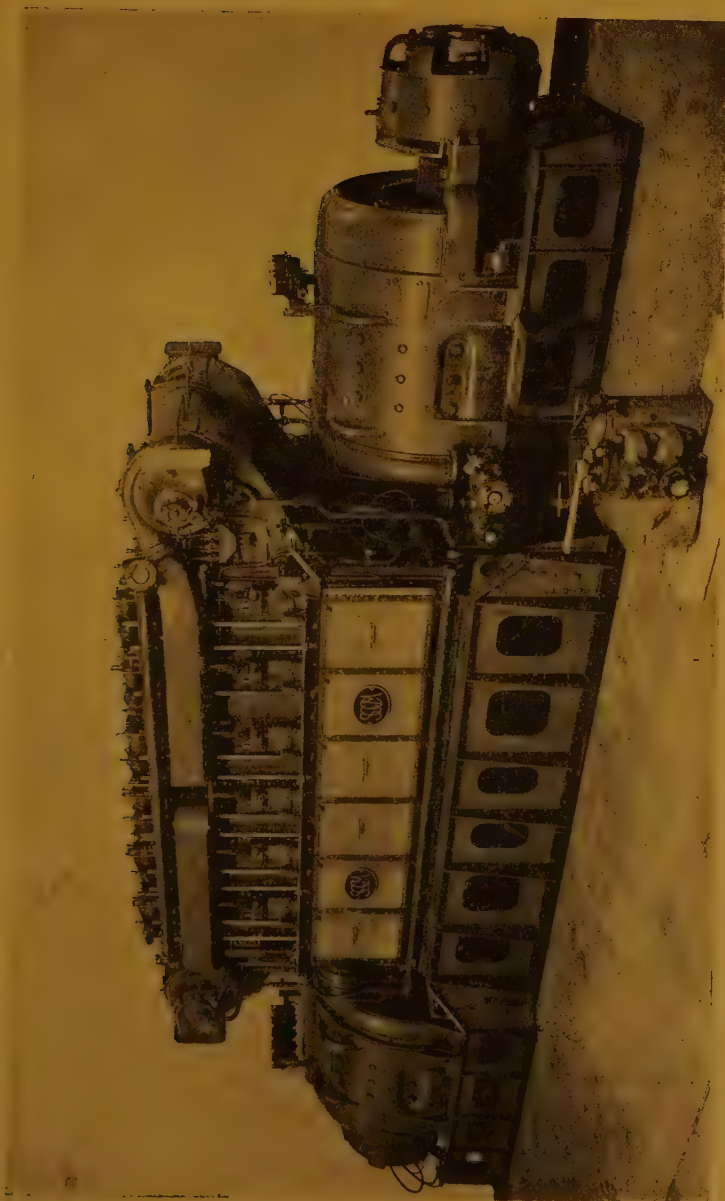


Fig. 125. — View of the motor group of two Diesel generators of the half-locomotive, figs. 124 and 126. Hourly rating of this group (half-locomotive) = 2 100 H.P.

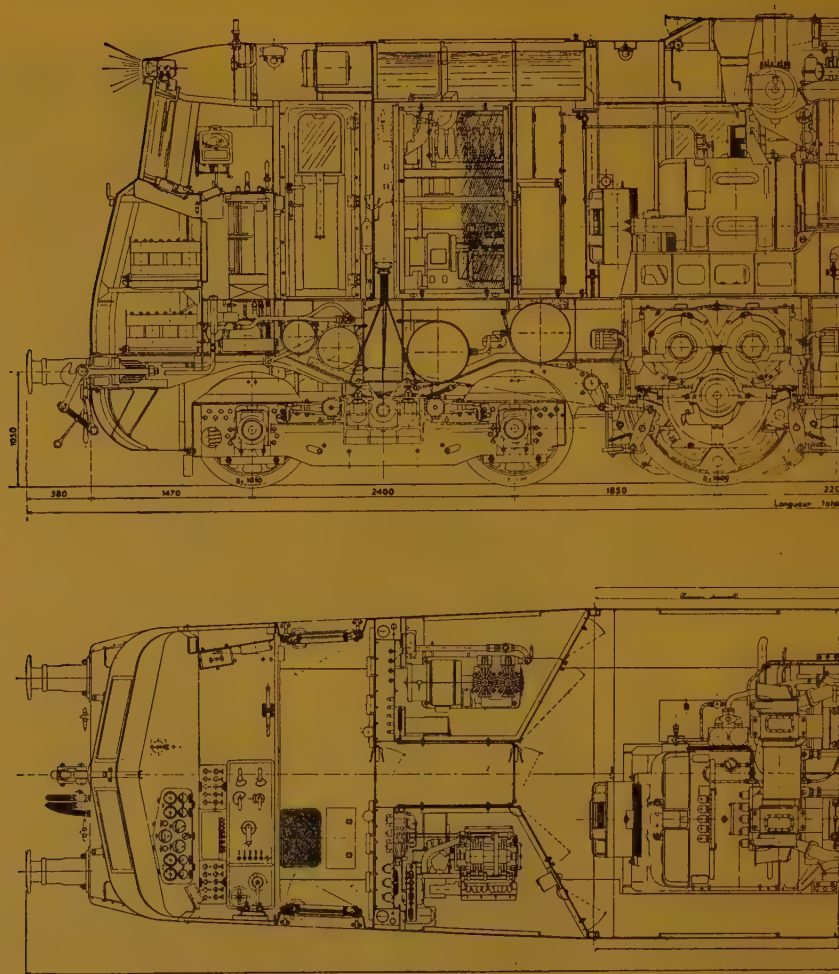
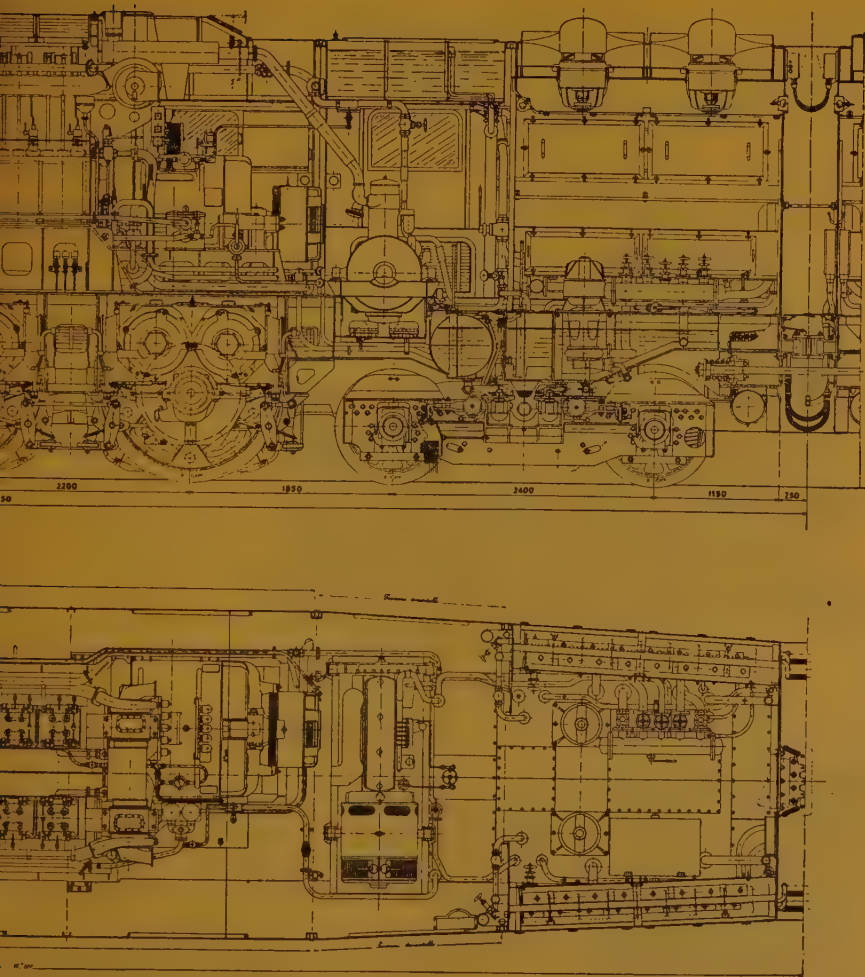


Fig. 126. — Longitudinal section and

the express service between Paris and Menton ⁽⁷⁴⁾ (total of six axles fitted) delivered in 1938 to the PLM (now SNCF — S.E. region) by the Fives-Lille, in collaboration with Swiss Winterthur (SLM),

Sécheron (SAAS) of Geneva and the « La Courneuve » Works (Seine); the « Société Générale de Constructions mécaniques » built the Diesel motors under MAN license.

⁽⁷⁴⁾ See *Revue Générale des Chemins de Fer*, Paris, May 1938 (article by TOURNEUR); *Revue Générale d'Electricité*, Paris, 19th March, 1938 (article by NEVEUX); *Bulletin Sécheron*, Geneva, No. 10, 1938.



the half-locomotives, fig. 124 (see fig. 87).

The characteristics of this locomotive are as follows :

Total power of
Diesel traction
motors (hourly,
at a speed of
700 r.p.m.) (4
× 1 050) . . . 4 200 H.P.
Max. speed (on
trials — 150
km./h.) . . . 130 km./h. (80 m.p.h.).

Weight in work-
ing order . . . 225 tons.
Adhesive weight
(6 × 16 tons). 108 tons.
Length over buf-
fers . . . 32.7 m. (107'3½").
Diameter of driv-
ing wheels . . 1 600 mm. (5'3").
Gear reduction ra-
tio . . . 1: 4.333.



Fig. 127. — Locomotive No. 208, 1-C₀+C₀-1 of the BLS Railways (Switzerland) (same locomotive as in fig. 44) with train, leaving Spiez for Lötschberg.

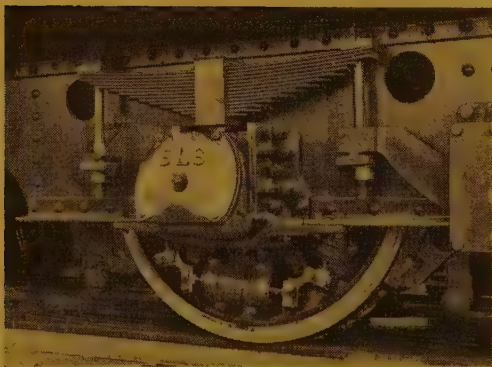


Fig. 128. — Driving axle of the BLS locomotives Nos. 207 and 208, figs. 44 and 127.

Fig. 122 shows a twin axle of this locomotive; fig. 124 the complete locomotive; fig. 126 a cross-section and plan of a half-locomotive, and fig. 125 the assembly of two Diesel-electric groups of a half-locomotive.

— two 1-C₀+C₀-1 (Ae⁶/₈) locomotives, Nos. 207 and 208, put into service in 1941 and 1943 respectively — during the world war — on the Swiss Bernese Alps, Berne-Lötschberg-Simplon line BLS, one of which is shewn in fig. 44 (No. 207) ⁽⁷⁵⁾ and the other, with a train, in fig. 127 : fig. 128 shows a driving axle mounted in the frame of these two locomotives.

(To be continued.)

⁽⁷⁵⁾ Fig. 44, BLS locomotive No. 207, shows the push-rod mechanism, but apart from this, locomotives Nos. 207 and 208 are identical (see text to the right of fig. 42).

Load compensating brake goes in service,

by C. D. STEWART,

Vice-President, Westinghouse Air Brake Company.

(*Railway Age*, October 23, 1947.)

The Illinois Central is about to place in service 400 hopper cars equipped with the new load compensating brake. The December 30, 1944 (see page 985), issue of the *Railway Age* carried an article that dealt principally with the purpose of this brake in comparison with the single capacity brake and covered only briefly the equipment involved and the manner in which it functioned.

study, followed by experimental installations on non-interchange cars, a very much simpler equipment has been produced. It is this equipment that is being installed on the new Illinois Central cars. These 400 cars will find their way over many roads in the near future.

By a unique piston arrangement it is possible for the first time to produce varying braking forces with a single

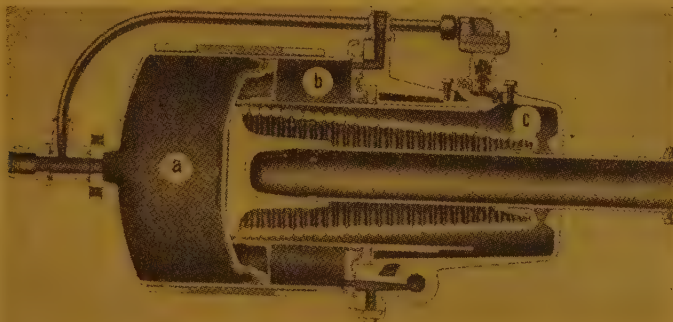


Fig. 1. — The brake-cylinder body showing the 12-in. piston chamber *a*; the chamber *b* around the hollow rod; and the chamber *c* inside the hollow rod.

The design, at that time in its early stage, contemplated two brake cylinders similar to those used with the empty-and-load brake equipment, but the pressure controlling means differed from that of the empty-and-load equipment in that braking forces were adjustable to intermediate loads as well as to the empty and fully loaded cars.

After many months of design and

brake cylinder. In this way the extra weight and handicap of a second brake cylinder with its notched push rod and latch box is avoided. This arrangement, also for the first time, employs less air for braking a loaded car than for an empty car — a very desirable situation.

To obtain the necessary braking force for the loaded car the single cylinder is 12 in. in diameter, and to conserve air

the nominal piston travel is 5 in. This compares with 8-in. nominal piston travel for the single-capacity brake and with 8-in. piston travel for the empty cylinder and 3-in. for the load cylinder of the empty-and-load brake. To better insure the desired piston travel at all times an automatic slack adjuster is employed. This also is the first time that the slack adjuster has been considered to be an indispensable part of a freight brake equipment.

The sectional view of the brake cylinder, Fig. 1, reveals the points of interest in its design. The cylinder body is of conventional design. The piston, however, has, in addition to the conventional 3-in. diameter hollow rod, a second hollow rod ($7\frac{1}{8}$ in. in diameter). This larger hollow rod in conjunction with a sealing gland in the non-pressure head forms an air chamber on the spring side of the 12-in. piston. The chamber *c* inside of the hollow rod is always subjected to atmospheric pressure. The chamber *b* around the hollow rod is subjected to pressures ranging from atmospheric to the maximum developed in the chamber *a* of the 12-in. piston.

The air under pressure in *a* is that which produces the braking force, and the degree of braking is produced by the amount of service brake reduction or by an emergency application, in the conventional manner.

The air under pressure in *b* counteracts the pressure in *a* in proportion to the respective pressures and piston areas in the two chambers. If the car is fully loaded the pressure in *b* will be atmospheric at all times. If the car is empty the pressure will be the same as in *a*. When the car contains intermediate loads the pressure will differ from that in *a* in proportion to the loading.

The « effective » piston area for the empty car condition is capable of producing a 50 to 60 per cent braking ratio with 50 lb. brake-cylinder pressure.

The « effective » piston area for the loaded car condition is capable of producing approximately 30 per cent braking ratio with the same pressure.

Braking ratios.

Thus the range of braking ratios is much narrower than with the single-capacity brake and consequently the slack producing forces in mixed trains is very much reduced. As for solid loaded trains, the braking ratio is 50 to 100 per cent greater than is now obtained on trains having the single-capacity brake and, therefore, the brake is very much more effective for the control of trains on heavy grades or for trains operating at higher speeds.

Since the brake cylinder will have air under pressure both in chambers *a* and *b* under certain conditions of car loading, it follows that air for operating the automatic slack adjuster cannot be taken from it in the conventional way. To meet this situation a cam-operated valve is mounted in the non-pressure head in such a location that the large hollow tubes engages it at the point of



Fig. 2. — Weighing gear in its non-functioning position.

nominal piston travel. The valve is opened by any movement of the hollow rod beyond this point and air under pressure from chamber *a* causes the slack adjuster to function in the conventional way and thereby takes up the slack in the brake rigging, restoring the piston travel to normal.

Air-pressure control.

The degree of air pressure that is admitted to chamber *b* is determined by the load-compensating valve and it, in turn, is automatically adjusted by the weighing gear. The gear is normally in free position so that car body movement due to running over the road will not cause false registration and also will not wear out the equipment. Fig. 2 shows it in such position. When the car is at its destination and having been loaded or unloaded, the locomotive is again attached, the brake system is of course charged before the car is moved. In the processes of building up the air

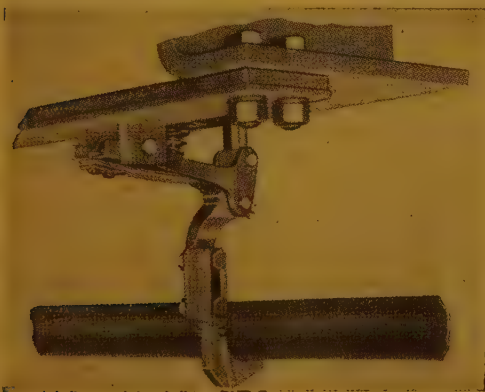


Fig. 3. — The hook engaging the bar on the car truck.

pressure from atmosphere to 45 lb., the weighing gear momentarily comes into action. The hook is raised, engages a bar on the car truck, Fig. 3, and thereby causes the mechanism in the compensat-

ing valve to assume a position that corresponds to the deflection of the car springs that in turn reflects the degree of car loading. When this function has been performed and the brake-system pressure rises above 45 lb., the weighing

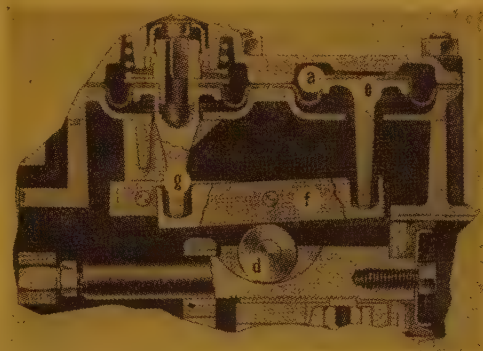


Fig. 4. — The scale beam mechanism within the compensating valve.

gear is disengaged and the compensating valve is locked in the position to which it has just been moved.

Fig. 4 illustrates the scale-beam mechanism within the compensating valve. The movable fulcrum *d* is positioned by the weighing gear in conformity with the car loading. The plunger *e* creates a force on the right hand end of the scale beam *f*, when air under pressure is present in chamber *a*, which is connected at all times with chamber *a* of the brake cylinder. The amount of force that is exerted at *f* is in direct proportion to the brake application, and the amount of force that is delivered at *g* is in proportion to the location of the fulcrum *d*. In the position shown the fulcrum is in the middle of the beam and consequently the forces at each end of the beam are equal. The upward movement of the left end of the beam opens an air-supply valve that permits the flow of air from the compensating reservoir to chamber *b* of the brake cyl-

inder, and because the forces on both ends of the fulcrum are equal the pressures in both chambers of the brake cylinder will be equal. The effective braking force exerted on the brake-cylinder push rod is that developed on the brake-cylinder piston area in chamber *a* which is not opposed by a like pressure in chamber *b*. When the car is fully loaded the fulcrum is directly under plunger *e* and then there is no

inder line, is a brake cylinder release valve. Its function is to vent the brake-cylinder pressure when cars are to be shunted, and to do this without loss of the reservoir pressures. This valve is manually opened by a trainman after the brake-pipe pressure has been vented. It will then remain open until brake-pipe pressure has been restored, when it automatically returns to normal position.

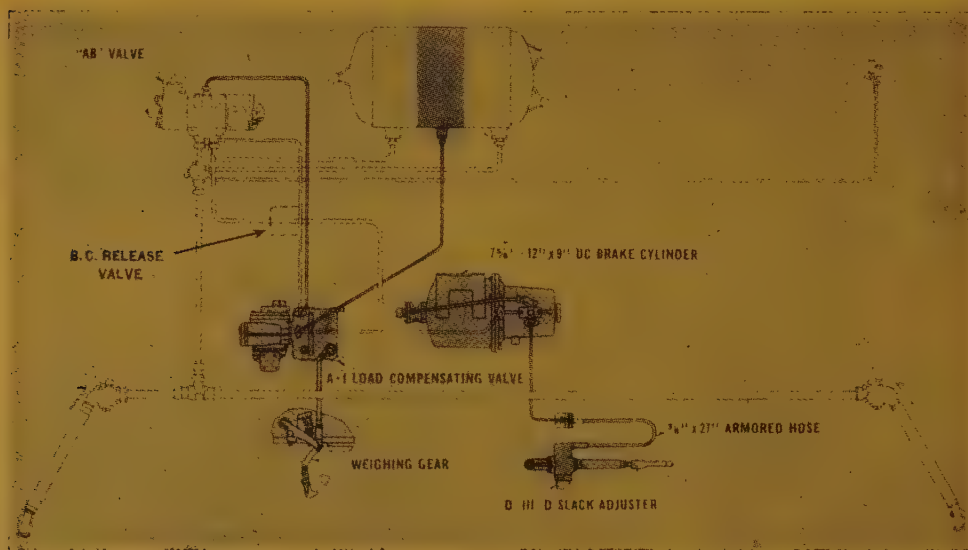


Fig. 5. — Piping diagram of the complete load compensating brake equipment.

force delivered to the left end of the scale beam. As a consequence there will be no air under pressure transmitted to chamber *b* of the brake cylinder.

Fig. 5 is a piping diagram of the complete load compensating brake equipment. It shows the relation of the various parts to each other and to the standard AB brake equipment. The shaded parts are those added to the AB equipment to provide the load compensating brake.

The valve dotted in, in the brake-cyl-

The A.A.R. has authorized the installation of a limited number of the load compensating equipment and also of the release valve. When a sufficient number of cars have been equipped with the former it plans to conduct road tests of 150-car trains under the empty and loaded conditions. Observations will be made both as to general brake performance and as to stopping distances from various speeds in comparison with the same performance with the present single-capacity brake.

Railway bridge with 100-ft. aluminium span.

(Engineering, December 5, 1947.)

For a number of years the Aluminum Company of America have desired to test, on a practical scale, the suitability of aluminium alloy as a constructional material for railway bridges. The considerations involved in this matter are not only those of cost; as the modulus of elasticity of aluminium is about one-third that of steel, aluminium structures are necessarily more flexible than

for exposed situations. The Aluminum Company does not contend that aluminium structures can compete in cost with those built of steel, although the price of aluminium has fallen during recent years, but it is naturally desirous to extend the field of application of the metal. In suitable cases, the increased cost may be offset by attendant advantages.



Fig. 1. — Old and new bridges; looking East.

those built from the latter material. The coefficient of expansion of aluminium is also about twice that of steel, the value for aluminium alloys ranging from 22 to 27×10^{-6} per degree C., as compared with 11 to 15×10^{-6} per degree C. for steel. This difference may introduce special design problems. Although it does not seem likely that aluminium will replace steel as a general structural material, some arguments may be put forward for its use in special cases. Its lightness may make it particularly suitable for lifting spans of bridges, and this quality may also simplify erection operations. By proper treatment it may also be made highly resistant to corrosion, making it a convenient material

An opportunity to make a full-scale practical test of aluminium alloy as a constructional material for railway bridges arose in connection with the reconstruction of the Grasse River Bridge, near Massena, in the northern part of the State of New York. This bridge carries a single-line spur railway, about two miles long, which connects the Massena plant of the Aluminum Company with both the New York Central and Canadian National Railways. The original bridge, which was built in 1897, consisted of two plate-girder spans, 50 ft. long and four Warren girder spans 100 ft. long; it can be seen in the foreground in Fig. 1, on this page. Owing to the increased weight both of the locomotives

and loaded waggons it became necessary to replace the original bridge by a stronger structure, and the opportunity was taken to incorporate an aluminium span in the new bridge, which can be seen behind the old structure in Fig. 1. The reason the new bridge lies at a higher level than the old is that the general reconstruction work, undertaken in connection with increase in the capacity

serve the behaviour of the aluminium span in relation to the neighbouring steel spans. The bridge is used only for freight service, operated by three 600-H.P. Diesel-electric locomotives, but the nature of the traffic will enable test runs to be made by heavy steam locomotives. The aluminium span, the position of which is clearly indicated by its lighter colour in Fig. 1, weighs only



Fig. 2. — Aluminium span being lifted into position.

of the line, included the enlargement of a marshalling yard, and the new layout enabled the railway grades to be improved by moving the position of the bridge 63 ft. to the east and raising the level by 20 ft.

The new bridge consists of seven plate-girder spans, one 90 ft. long, four 100 ft. long, and two 75 ft. long. The co-operation of the railway company was secured in the decision to construct one of the 100-ft. spans entirely of aluminium alloy. The situation of the bridge in the neighbourhood of the Massena works is particularly favourable in enabling the Aluminum Company to ob-

53 000 lb., as compared with 128 000 lb. for the neighbouring steel span of the same length. The relative costs of the two spans have not been furnished, but in the particular circumstances of this experimental installation the matter is of secondary importance.

In an article in the December, 1946, issue of *Civil Engineering*, the monthly journal of the American Society of Civil Engineers, Mr. SHORTRIDGE HARDESTY, M.A.S.C.E., and Mr. J. M. GARRELTS, M.A.S.C.E., point out that, although the Grasse River Bridge incorporates the first example of an all-aluminium bridge span, aluminium alloy was used as long



Fig. 3. — Hand fitting flange cover plates.

ago as 1933 for bridge decking. In that year, the steel and wood floor system of the Smithfield-street Bridge, Pittsburg, was replaced by an aluminium-alloy deck. As the weight was only half that of the original floor, the old steel trusses and masonry foundations were made safe for heavy modern traffic. Although the aluminium-alloy deck is exposed to a corrosive industrial atmosphere, it is still satisfactory after 14 years of service. Studies of the use of the material have been made in connection with various lifting spans and other bridge features in which dead weight was an important factor, and although these have not resulted in practical applications they have shown that aluminium alloy has strong claims to consideration in special cases.

The Grasse River span is constructed of an alloy known as 14S-T. This material, which has been in use for more than 25 years, combines high strength with good resistance to atmospheric cor-

rosion. It has been used for heavy-duty forgings in excavators and other machines, and has found considerable application in the manufacture of aeroplane parts. It was also used for the floor system of the standard pontoon-bridge units of the United States Army. The material contains 4.4 per cent. of copper; 0.8 per cent. of silicon; 0.8 per cent. of manganese; and 0.4 per cent. of magnesium. Typical mechanical properties are: ultimate tensile strength, 70 000 lb. per square inch; yield strength (2 per cent. set), 60 000 lb. per square inch; elongation in 2 in. ($\frac{1}{2}$ in. diameter specimen), 13 per cent.; Brinell hardness (500 kgr. load with 10-mm. diameter ball), 135; shearing strength, 42 000 lb. per square inch; and modulus of elasticity 10 600 000 lb. per sq. inch. The average coefficient of thermal expansion, between -50 deg. F. and 150 deg. F., is 0.0000125 per deg. F. and the weight, 174 lb. per cubic foot. The resistance to corrosion of 14S-T alloy plates used in the construction of the span

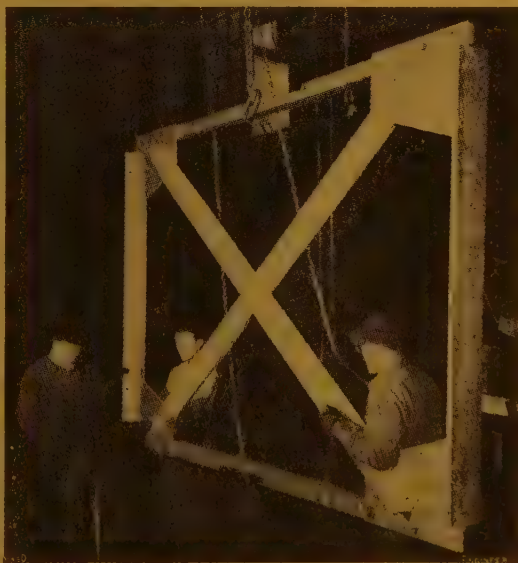


Fig. 4. — Assembling cross frame.

was increased by employing the process known as «Alcladding». In this, a layer of a different alloy, of greater corrosion resistance, is rolled on to both surfaces of the plate. The layer, which has a thickness of about 5 per cent. of the finished plate, is of such chemical composition that when it is cut or broken, and is wetted by a conducting liquid, such as salt water, a local electric circuit is set up, resulting in the sealing of the defect. The action also serves to protect the rivet ends, which are not Alcladded.

by $\frac{3}{8}$ in. angle is fixed between the vertical stiffeners on the inside of each girder, about 30 in. from the top of the web. The top lateral struts are 6 in. by 4 in. T-sections, with 8 in. by 6 in. T-diagonals, the lower lateral system consisting of 6 in. by 4 in. T's both for struts and diagonals. For the end cross frames, the top struts are made up to two 5 in. by 3 in. angles and the bottom struts of two 4 in. by 3 in. angles; the diagonals consisting of two 6 in. by 3 in. T's. There are seven intermediate cross frames with 6 in. by 4 in. struts and



Fig. 5. — Transporting completed aluminium span.

The general construction of the span can be seen from Fig. 2, an page 250, which shows it being lifted into place during erection. It consists of two plate girders 10 ft. deep and 100 ft. long. The web plates, $\frac{3}{4}$ in. thick, are made up of four 25-ft. sections. The flange angles are 8 in. by 6 in. by $\frac{5}{8}$ in., and the web-stiffening angles are 5 in. by $3\frac{1}{2}$ in. by $\frac{7}{16}$ in., this latter dimension being increased to $\frac{3}{4}$ in. for the end stiffeners. The cover plates are 14 in. wide by $\frac{5}{8}$ in. thick. To stiffen the deep aluminium web, a horizontal 5 in. by $3\frac{1}{2}$ in.

diagonals consisting of one 6 in. by 4 in. T-section.

The design of the span was worked out in general accordance with the recommendations given by the late Leon S. MOISSEIFF in his manual entitled *Design Specifications for Bridges and Structures of Aluminium Alloy 27 S-T*. As the mechanical properties of 14 S-T alloy, of which the span is built, are superior to those of the 27 S-T alloy on which MOISSEIFF's calculations were based, it was considered that the new design would have an ample factor of

safety. The basic unit stress in tension was taken as 21 000 lb. per square inch, the value used by MOISSEIFF. Consideration had to be given to the properties and behaviour of the neighbouring steel spans. If the live-load unit stresses were the same for a steel girder as for an aluminium girder of equal depth, the deflection of the latter would be about 2.8 times that of the former. This greater deflection could be reduced either by increasing the depth of the girder or decreasing the live-load unit stress.

The span is designed for an extreme fibre tension, in rolled sections, girders and built-up sections, of 20 800 lb. per square inch. The shear stress in the plate-girder webs is 12 500 lb. per square inch; in cold-driven rivets, 10 000 lb. per square inch; and in hot-driven rivets, 8 000 lb. per square inch. The two types of rivet are made from different material, as is explained below. The dead load on each girder of which the span is made up is 27 500 lb.; the live load, 220 300 lb.; and the impact, taken



Fig. 6. — Drilling aluminium web plates.

There were limitations to the use of either of these procedures. An appreciable reduction in unit stress would not have been practicable on the score of expense, and a considerable increase in depth would not have been consonant with a satisfactory appearance for the completed bridge. The steel girders are 9 ft. deep, and as a compromise it was decided to make the aluminium span 10 ft. deep. This procedure did not give the maximum economy in material, but it was within the economic range, reduced deflection and had little effect on the appearance of the completed bridge. It will be clear from Fig. 1 that the aluminium span is deeper than the others.

as 55 per cent. of the live load, 122 200 lb. The total maximum shear load is accordingly 370 000 lb. The maximum dead-load moment is 669 000 ft.-lb.; the maximum live-load moment, 4 628 000 ft.-lb.; and the maximum impact-load moment, 2 569 000 ft.-lb. These values make up a total maximum moment of 7 866 000 ft.-lb.

At the time the design of the bridge was being worked out, heavy plate of Alclad 14 S-T alloy had never been produced in widths as great as 10 ft., and the Aluminum Company accordingly rolled a number of plates 10 ft. wide, $\frac{3}{4}$ in. thick, and about 26 ft. long, and submitted them to test and examination for physical properties and flatness.

They were satisfactory, and it was on the basis of these plates that the decision was made to form the girder webs of four plates 25 ft. long. It was not considered desirable to attempt to exceed the 26-ft. length of the test plates. The maximum live load on the bridge is imposed by 70-ton loaded waggons, and under this condition the deflection of the span is 1.25 in., as compared with 0.45 in. for the steel spans. The aluminium span is built with a camber of $1\frac{1}{4}$ in. at the centre. The span was designed by the Gen-

pletely assembled in the shops and shipped and erected as a complete unit.

No operational difficulties were encountered by the Bethlehem Steel Company in the construction of the span and they were able to utilise their standard tools and methods. The only piece of special equipment required was an electrically-heated furnace for the rivets which were driven hot. Most of the rivets used were $\frac{7}{8}$ in. in diameter, made from A 17-S-T aluminium alloy. This material contains 2.5 per cent. of copper



Fig. 7. — Construction of flange assemblies for web plates.

eral Engineering Department of the Aluminum Company, Pittsburg, Messrs. HARDESTY and HANOVER, of New York, acting as consulting engineers. All material was supplied by the Aluminum Company and the span was manufactured by the Bethlehem Steel Company at their works in Rankin, Pa.; it was also erected by this firm. The steel spans were built in the same shops and an incidental advantage of the aluminium construction was illustrated by the fact that, owing to weight considerations, it was necessary to ship and erect the girders of the steel spans separately and assemble the lateral bracing in the field; whereas the aluminium span was com-

and 0.3 per cent. of magnesium. These rivets were driven cold by means of an 80-ton air-operated squeeze ram. When driven, they have an ultimate shearing strength of 33 000 lb. per square inch. The hot-driven rivets were used in positions in which the ram could not be used, notably for the connections between the gussets of the cross frames and the inside vertical stiffener angles of the girders. These hot-driven rivets were made from 53 S-W aluminium alloy, which contains 1.3 per cent. of magnesium, 0.7 per cent. of silicon, and 0.25 per cent. of chromium. When in position they have an ultimate shearing strength of 24 000 lb. per square inch.

They were driven by pneumatic hammers at a temperature of about 1 040 deg. F. They develop their strength through the «quenching» received by contact with the cold metal and tools.

All holes were drilled in the aluminium plates or sections which were $\frac{1}{2}$ in. or more in thickness; thinner parts were punched. In both cases, the holes produced were $\frac{11}{16}$ in. in diameter and were afterwards reamed when the parts to be connected had been assembled together. The operation of the initial

rivets. In order to ensure complete bearing, the cover plates were carefully fitted by hand. This operation is illustrated in Fig. 3, page 251. The $\frac{11}{16}$ in. drilled holes were first aligned by passing an $\frac{11}{16}$ -in. diameter reamer through them and then enlarged with a $\frac{57}{64}$ -in. reamer. The rivets were then inserted and closed by the 80-ton squeeze ram visible in Fig. 7, on page 254.

The next stage was the fitting of the flange assemblies to the web plates. The lower flange assembly was secured



Fig. 8. — Inserting web plates in lower flange assemblies.

drilling of two of the web plates together is illustrated in Fig. 6, on page 253. The first stage in the construction of the span was the building up of the top and bottom flange assemblies for the web plates. This operation is shown in Fig. 7, on page 254. The flange angles were first bolted together against spreaders $\frac{5}{16}$ in. in thickness, that is, $\frac{3}{16}$ in. greater than the thickness of the web plates which were subsequently to occupy their position. The cover plates were then fitted to the flange angles, all metal-to-metal contact surfaces being covered with an aluminium-pigmented caulking compound containing zinc chromate. Excess of the compound was squeezed out during the fitting and driving of the

by clamps to rails bolted to the shop floor, as shown in Fig. 8 above, the clamps being set so that the flange was given the necessary $1\frac{1}{4}$ -in. camber. The web plates were lowered into position, the stiffener angles fitted, and the top flange assembly lowered into position, as shown in Fig. 9, on page 256, in which one of the flange assemblies for the second girder can be seen in the foreground. When the girder had been riveted up and completed, it was laid on its side and the cross frames were secured to the inside stiffener angles, the second girder, previously completed, then being lowered into position and riveted to the cross frames. The manufacture of one of the latter is illustrated

in Fig. 4, on page 251. This shows the fixed machine used for riveting the gusset plates and which, when convenient, was used instead of the 80-ton squeeze ram slung from a crane, which is shown in Fig. 7, page 254. After completion, and before shipment, the span was painted with a priming coat of zinc chromate and two coats of aluminium

of lifting only one girder of the steel spans. These were erected separately, and the cross frames and laterals of the steel spans were assembled on site by men working on suspended platforms. It cannot be assumed that the facility with which the aluminium span was erected would represent a saving in over-all cost which would balance its



Fig. 9. — Assembling top flanges on web plates.

paint. A 6-ft. wide panel between two vertical stiffeners was left bare in order that the weathering properties of the aluminium-alloy parts could be studied.

The completed span weighs 53 000 lb. and was shipped and handled as a complete unit. It was transported to site by rail on two flat cars, as shown in Fig. 5, page 252, and was lifted into position by a 30-ton locomotive crane. The handling operation is illustrated in Fig. 2, on page 250. The crane was capable

greater manufacturing cost, but it is possible that, in some special cases, this simplification of erection procedure might, in itself, justify the employment of aluminium as a structural material. The span is carried on steel rockers and, in order to allow for the high coefficient of expansion, these are made $13\frac{1}{2}$ in. high, permitting an end movement of 2 in. on each side of the vertical. The rocker is set to be in the vertical position at 100 deg. F.

Central Line extensions into Essex.

(From *The Railway Gazette*, December 19, 1947.)

The formal opening on Friday, December 12, 1947, by the Minister of Transport of the new Central Line extension to Woodford and Newbury Park was an event of more than usual interest for a number of reasons. First, it represented the last new construction to be brought into public use under private ownership. Secondly, it represented the completion of the tube railway tunnel construction programme for the London area, with the exception of the short line between Drayton Park and Finsbury Park. Thirdly, and particularly from the civil engineering viewpoint, it was of unusual interest as the first tube railway to be lined with reinforced-concrete segments.

It may be recalled that this North-East London scheme, designed in 1935 to provide adequate travelling facilities for the rapidly-growing population in the area east of the Lea Valley and north of the main road to Brentwood and Chelmsford, was made possible by close co-operation between the L.N.E.R. and London Transport. London Transport is projecting its Central Line services from Liverpool Street in stages eastwards largely by taking over for operating purposes, and converting to electric traction, the L.N.E.R. line to Ongar and the Fairlop Loop. A new tube railway was built from Liverpool Street to Stratford and brought into operation on December 4, 1946. This was extended in tube to Leyton and thence over L.N.E.R. electrified surface tracks to Leytonstone on May 5, 1947. The present openings comprise the further extension over electrified L.N.E.R. surface lines of Central Line trains to Woodford and also the bringing into use of a new tube from

Leytonstone to Newbury Park, where it comes to the surface to form a junction with the L.N.E.R. Fairlop Loop Line. The L.N.E.R. sections have been resig-nalled, and electrification is on the standard London Transport 600-volt d.c. fourth-rail system. Power supply for the extension has necessitated the provision of six additional substations.

The new tube line.

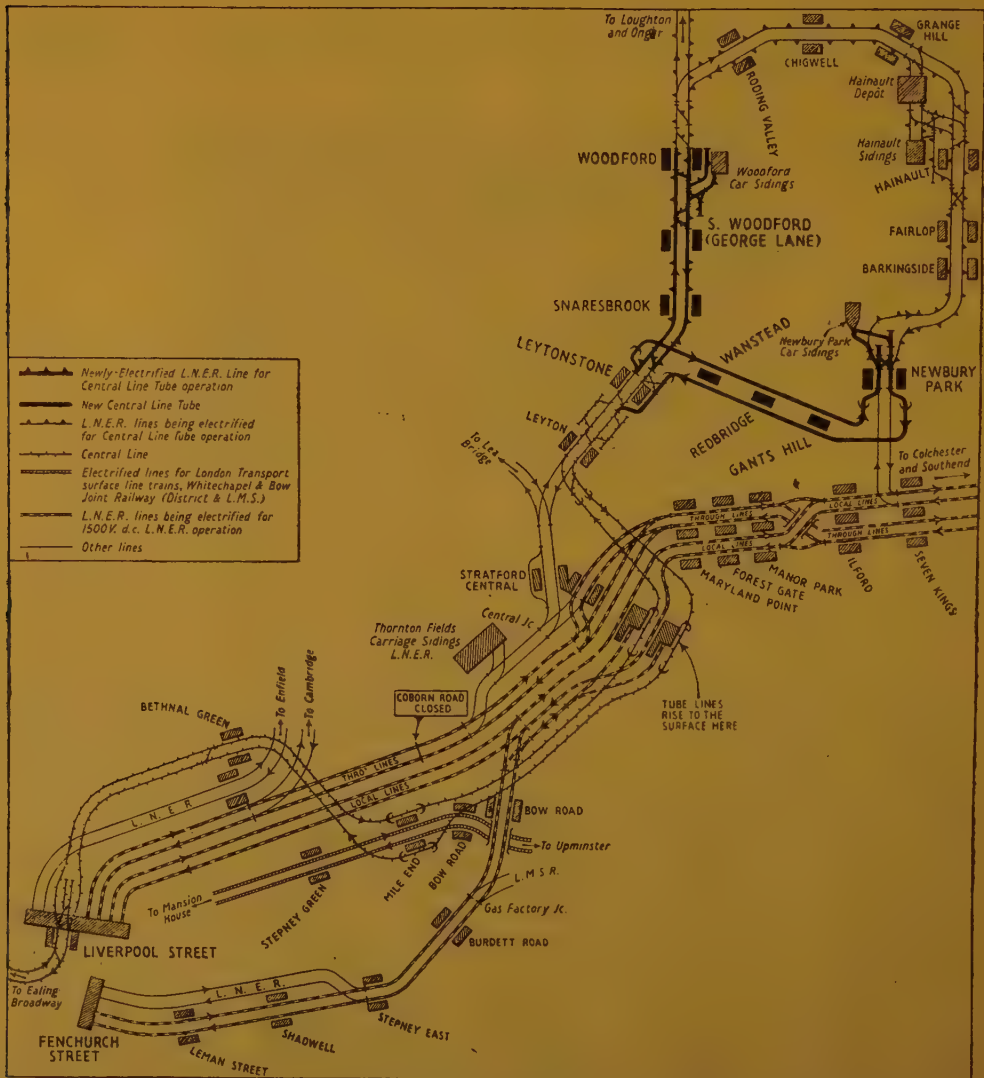
The new section of tube line to Newbury Park begins just beyond Leytonstone by a descent in reinforced-concrete cutting at 1 in 45 on each side of the existing L.N.E.R. line. This tube section, which is four miles long, has three intermediate stations at Wanstead, Redbridge, and Gants Hill. The platforms at these three stations are all at tube height, namely, 1 ft. 8½ in., but on the L.N.E.R. surface lines the platforms have been brought to the compromise height of 2 ft. 9 in. above rail level.

This tube line was nearly completed at the outbreak of war, but the track was not laid. In the autumn of 1940 Lord Beaverbrook approached the London Passenger Transport Board with a view to exploring the possibility of underground accommodation for the protection of vital production machinery, and this uncompleted tube was selected and pronounced capable of conversion. The work of equipment was begun in November, 1940, and a factory of about 300 000 sq. ft. of floor space was opened in March, 1942. The Ministry of Aircraft Production selected the Plessey Co. Ltd. (which had an overground factory at Ilford) to use the underground site as an aircraft component factory, and as

such it served throughout the remainder of the war.

At Wanstead the ticket hall is at the corner of Eastern Avenue and High Street, above ground, and two escalators

with a rise of 60 ft. provide the means of communication to a standard deep-level tube station; there is a fixed stairway between them. The booking hall is some 40 ft. square, and the station build-

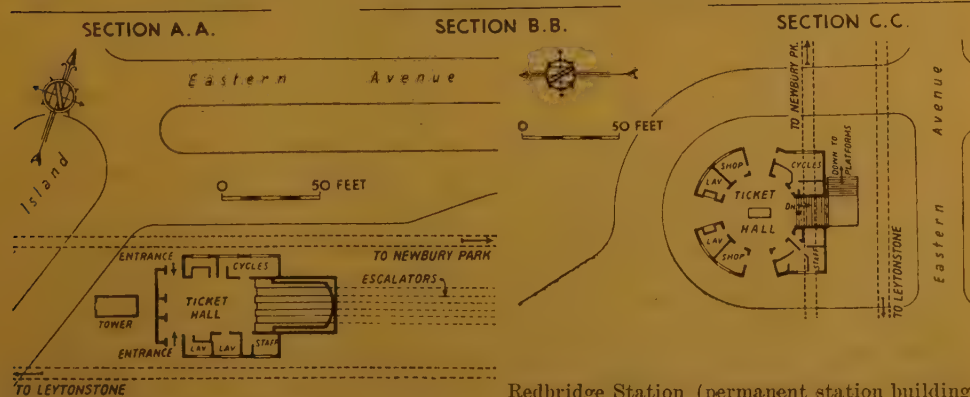
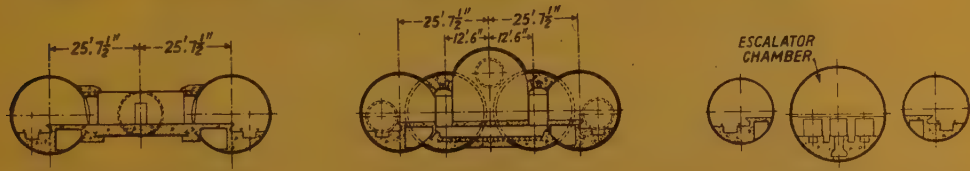
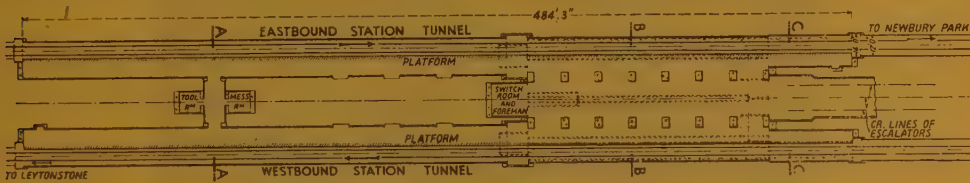
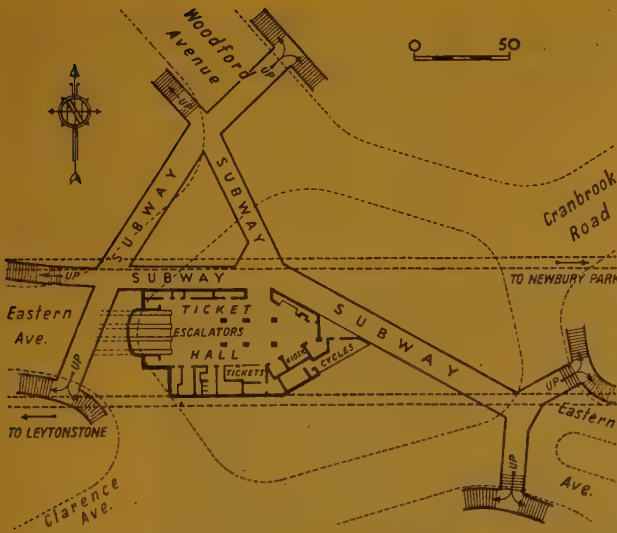


Sketch map (not to scale) showing the new Leytonstone to Newbury Park tube, and the newly electrified Leytonstone to Woodford line, in relation to existing lines.

THE STATIONS
OF THE NEW
TUBE RAILWAY
BETWEEN LEYTONSTONE
AND NEWBURY PARK.

Left : Plan at subway level of
Gants Hill Station showing
the six street entrances and
sub-surface ticket hall.

Below : Plan and cross-sections
of Gants Hill Station
at platform level.



Wanstead Station.

Redbridge Station (permanent station building
still under construction).

ing has been adapted from the Plessey factory entrance building, for the sake of economy and speed. This building has large concrete-framed windows. The interior tiling, etc., of the station is in cream and green.

The new ticket hall at Redbridge is built above the surface on an island at the junction of Redbridge Lane and Eastern Avenue, and a footbridge over the latter will provide access from the

is on a more elaborate scale than usual, there being a large concourse between the platforms at the foot of the escalators with a high arched roof supported on 16 columns. This hall is nearly 50 yd. long. There are three escalators, with a 32-ft. rise. The interior tiling of the station is in cream and yellow.

All three stations are situated on Eastern Avenue, a relatively new arterial road leading eastwards out of London.



Sloped reinforced concrete cutting approaches to the tubes under construction at Leytonstone Station.

south side. The lines come so close to the surface here that a short stairway connects the ticket hall and the island platform which, with the tracks, is in a reinforced-concrete cut-and-cover tunnel. The permanent surface building at Redbridge has been held up by steel shortage, and a temporary booking hall has been built, therefore, with a covered way approach to the stairs. The interior tiling of this station is in cream and blue.

The station at Gants Hill is of the Piccadilly Circus type, below the centre of a road traffic roundabout, with subway entrances from the adjacent street corners. The low-level part of the station

At Newbury Park, a temporary booking office has been built alongside the old station, and a new station incorporating a staff canteen is to be built later. A new bus forecourt is also being constructed, including a reinforced-concrete roof under which buses will discharge their passengers, who will enter the station under cover.

Reinforced-concrete tube segments.

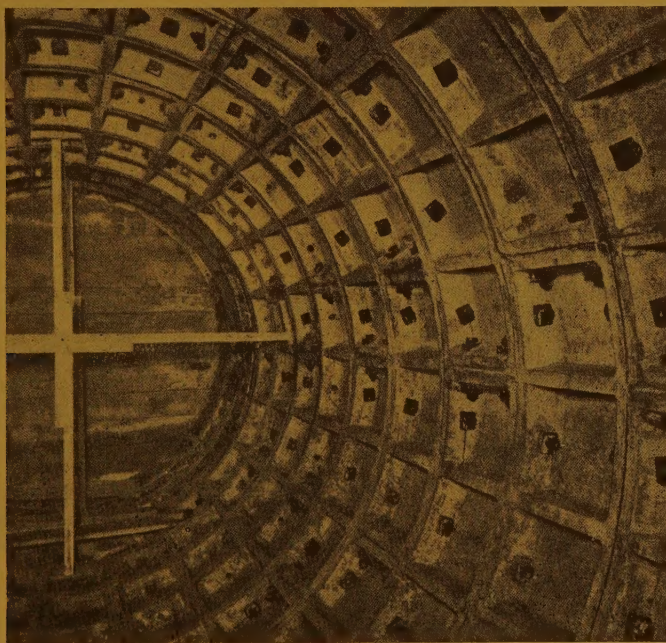
An unique feature of this section of tube is that reinforced-concrete lining has been used for $2\frac{3}{4}$ miles of running tunnel. Because of the increased thickness of the flanges of the concrete lining, signal apparatus cannot be nested into

the segments as it can in those of cast iron, and the concrete lining is accordingly made 12 ft. 3 in. internal dia. Each ring has the same overall dimensions as the normal cast-iron ring, and the reinforced-concrete rings are lighter than the cast iron, as well as cheaper. The external face of the concrete is coated with a bituminous solution to pre-

portion of the tube consists of standard cast-iron rings, of which some 13 000 were used.

Central line services.

As a result of the replacement of Wood Lane (short-platform) Station by the new White City (long-platform) Station on November 23, 1947, and the open-



Tube constructed in pre-cast reinforced-concrete segments.

vent attack by any impurities in the soil. One of the initial difficulties encountered in developing this type of lining was to provide sufficient strength in the circumferential flanges to resist the very considerable thrust from the rams of the shields, and much of the reinforcing has been devoted to this purpose. In the casting of the segments vibratory methods were used. In all, nearly 9 000 of these rings were used. The remaining

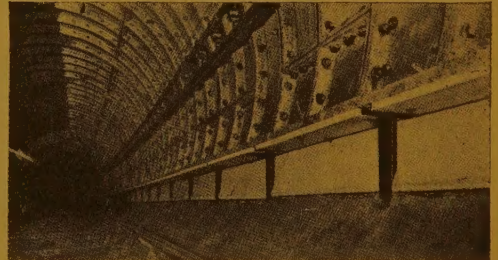
ing of the Newbury Park and Woodford extensions, all Central Line trains have been increased from 6 cars to 7 cars. There are some peak-hour 8-car trains, making a number of journeys during peak times. The service provides for more than 180 trains a day each way on each of the two new sections. The rush-hour frequency on each section is 16 trains an hour each way (i.e., a train every $3\frac{1}{2}$ -4 min.). West of Leytonstone



Standard cast-iron tube with permanent way laid, but before installation of conductor rails.



Illuminated diagram and power frame in the new 59-lever Newbury Park signal box. Except for Woodford Station and Woodford Junction, all boxes between Leytonstone and Newbury Park, via Grange Hill, are now staffed by London Transport.



Sound-absorbing panels in tube tunnel, which, in conjunction with 300-ft. rails, reduce noise in the carriages.



Platform view at Wanstead Station with a staff train passing through. The fluorescent lighting will be noticed.

the two services combine to 360 trains a day each way. There is no reversing at Leytonstone, all trains reaching there from the City proceeding either to Woodford or to Newbury Park. The inter-station time between Leytonstone and Newbury Park is 10 min., and between Leytonstone and Woodford is 7 min.

Level crossings closed.

As a result of this increase in the train services from six or eight to 16 to 32

trains an hour on the Woodford line, it became necessary to close level crossings at Eagle Lane, George Lane, and Snakes Lane, in the borough of Wanstead and Woodford, and this was done as from November 30. There are pedestrian subways at each of these points. The footway across the railway at Marlborough Road also has been closed, and until the erection of a footbridge at this point is completed, pedestrians have to use the subway at George Lane.

Vehicular traffic and the bus service formerly using Eagle Lane level crossing have been diverted along Hollybush Hill and New Wanstead Road, or along Woodford Road and High Road to Southend Road. It is hoped, however, that the permanent route under the railway bridge at High Street, Wanstead, now closed to vehicular traffic, but open for pedestrians, will be completely available

very soon when the raising of the low bridge is completed. Traffic at George Lane crossing has been diverted along Southend Road, *via* Gates Corner or Chigwell Road, and traffic formerly using Snakes Lane has been diverted along St. Barnabas Road, Broadmead Road bridge, and Charteris Road. Work on a permanent bridge at George Lane has been begun.

L.N.E.R. steam services.

As already announced, the Fairlop Loop was closed to rail traffic on November 30. A revised steam service of L.N.E.R. trains was introduced on Sunday, December 14, between Woodford, Loughton, Epping, and Ongar. Woodford thus becomes the interchange station between L.N.E.R and London Transport trains, pending the completion of further electrification.

CORRIGENDUM.

In the *Bulletin* for October 1947, page 937, 2nd. Col., 4th. line, there is :

General Electric Company;

Please read :

General Railway Signal Company.

